Appendix 1 : Mycorrhizae Associated with Oak: A literature Review

The purpose of the following descriptions is to determine if the identified ectomycorrhiza have been previously found in oak forests.

Oak species are considered to be strongly mycorrhizal in nature (Schütt et al, 1992). Brief reviews of the literature show that although considerable information is available concerning the fungal fruiting bodies in oak woods, very little is currently known about the seasonal demographics of oak-ectomycorrhizae. Many times the only descriptor for a species in the literature was to state it was found in "deciduous" or "coniferous" forests. This was frustratingly vague, but also an indication that the species was fairly common.

Despite the fact that the first collecting year was extremely dry and the second year was extremely wet, neither ideal for maximal fungal production, the distinct seasonal variations may provide clues to the adaptability and survivability of various mycorrhizal species. The discovery of fall fruiting bodies in the Merzalben oak forest was used to indirectly suggest possible mycorrhizal presence, and vica versa, the presence of ectomycorrhizae suggests fruiting body potentials. But the absence of the corresponding fruiting bodies does not mean the identification of the ectomycorrhizal species must be wrong. Without the benefit of genetic analysis to determine allelic identity, and direct tracing to fruiting structures, all species identifications are tentative, but the genus and species assigned fairly agree with the gross morphological and microscopic data currently available of representative samples using Agerer's micrographs (Agerer, 1987-1995) and other available resources, as listed.

Some succession crossover of mycorrhizae from one tree species to another is possible. In this study area, the forest was originally a mixed spruce, oak, beech stand but through forestry practices it has artificially evolved into a primarily a mixed beech / oak stand with remnants of spruce. Many of the *Piceirhiza* species isolated from the oak roots were found, in the literature, to be symbiotic association with *Picea abies*. These species for the most part were rarely or seldom present on the oak roots implying a less than satisfying mycorrhizal relationship, although some (*Piceirhiza chordata*) were abundant, suggesting a good cross over. Other ectomycorrhizal species were found in the literature to be commonly in association with *Fagus sylvatica* and for the most part, these species (*Fagirhiza*) were found to be numerous on the oak roots possibly either because they are better suited to oak than the less successful *Picea* ectomycorrhizae or because of the close proximity of *Fagus* species in the mixed forest.

Some mycorrhizal species were probably transitional introductions *(Dermocybe cinnamomea, Elaphomyces muricatus, Entoloma sinuatum, Gomphidius roseus, Pinirhiza rufomaculata, Pisolithus tinctorius, Tetraberlinaerhiza, Tomentella albomarginata*) due to possible accidental anthropogenic spore transfer (on machinery, cars, hiking boots ...) since they were rare and are known to be mycorrhizal on trees distinctly absent from the area. Spore, sporocarps and fragment transfers can also be effected by animal vectors. Forest mice (*Apodemus flavicollis* and *Chlethrionomys glareolus*) can transfer adhering and undigested fungal spores (i.e.- Tuber , *Elaphomyces, Endogone, Genea* and

Choiromyces sp.) directly to the roots sphere in connection with their tunneling activities (Blaschke, 1987) which may account for scattered fungal appearances, widespread dispersal and natural tree inoculations.

Some ectomycorrhizal species associated with *Quercus* sp. elsewhere where not found in Merzalben (*Amanita phalloides, Collybia dryophila, Lactarius serifluus, Lactarius quietus, Leccinum quercinum, Lycophyllum decastes, Polyporoletus sublividus, Populirhiza pustulosa, Ramaria subbotrytris, Suillus luteus, Tricholoma acerbum*). They were absent possibly due to a limited geographic range (elevation), ecological factors (acidity, moisture), genus specificity, or the limited sampling area Some species normally associated with *Fagus sylvatica* were also noteably absent (*Cortinarius cinnabarinus, Fagirhiza vermiculiformis, Fagirhiza oleifera, Geastrum fimbriatum, Tricholoma acerbum, Trichloma sciodes*). Again perhaps for the same general reasons stated above.

Ranking of Mycorrhizal Abundance:

Not found / Absent
Very Rarely
Rarely
Seldom
Occasionally
Often
Frequently
Abundant
Common
Very / Extremely Common

Mycorrhizal Fungi of Oak in this study and in the literature.

Amphinema byssoides (Pers.) J. Erikss. (Syn. *Thelephora byssoides* Fr.) Mycorrhizal on *Picea abies* L. Karst. Fruiting bodies are widespread on rotten wood and in litter of coniferous forest and also occur in poor deciduous forest (Agerer 1987-1995) Seldom found as a mycorrhiza on *Quercus petraeae* . No fruiting bodies seen. (Wilson, 2003) Basidiomycota, Basidiomycetes, Agricomycetidae, Polyporales, Atheliaceae (CABI Bioscience, 2002)

Boletus edulis Bull. Fr. (44 variants) (CABI Bioscience) Mycorrhizal on *Picea abies* (= Fichte = Spruce). Fruiting bodies prefer poor acidic, sandy and silicatous soils but also on other soils if the upper soil is acidic except at levels of high metal saturation in deciduous forest, *Fagus* (beech) woods (Agerer 1987-1995). Occasionally mycorrhizal on *Quercus petraeae* oak. *Boletus edulis* abundantly present as fruiting bodies in moist fall weather more so on limed than unlimed forest soil. *Boletus erythropus* was present on limed soil in dry fall weather and on unlimed soil in moist fall weather. *Boletus impolitus* present mostly on limed but also on unlimed soil in moist fall weather. (Wilson 2003).

Byssocorticium atrovirens (Fr.) Bondartsev & Singer Ex Sing. Mycorrhizal host: *Fagus sylvatica* L. (= Buchen = Beech) Easily recognized by its steel blue color (Agerer 1987-1995) (syn: Thelephora atrovirens Fr. 1828) Basidiomycota, Basidiomycetes, Agaricomycetidae, Polyporales, Atheliaceae (CABI Bioscience, 2002). Rarely mycorrhizal on *Quercus petraeae* (Wilson 2003)

Cenococcum geophilum Fr. Mycorrhizal on *Picea abies*. No known fruiting body. (Agerer 1987-1995) Copious soil spore production. Most Common *Quercus petraeae* oak mycorrhiza (Wilson, 2003)

Cortinarius armillatus (Fr.: Fr.) Fr. Mycorrhizal on *Betula pendula* Roth. (=Birke =Birch) Prefers acid sandy soil of deciduous birch forests (Agerer 1987-1995).

Occasionally strongly present on *Quercus petraeae* as mycorrhizae, Cortinarius sp. fruiting bodies found in oak forest (Wilson, 2003)

Cortinarius bolaris (Pers.: Fr.) Fr. *Mycorrhizal on Fagus sylvatica* perfering acid humus with fruit bodies under beech and oak trees (Agerer 1987-1995) Occasionally mycorrhizal on limed *Quercus petraeae* (Wilson, 2003)

Dermocybe cinnamomea (L.: Fr) Wünsche. Mycorrhizae on *Picea abies* (Agerer 1987-1995) Cortinariaceae member. (Waller & Agerer, 1993). Autofluorescence of emanating hyphae in UV: slightly bluish with bright copper-orange tint here and there. Rarely found on limed *Quercus petraeae* (Wilson 2003)

Elaphomyces muricatus Fr. Common mycorrhiza on *Fagus sylvatica* mostly in humic mineral soil layer and very similar to *Piceirhiza glutinosa* which occurs as mycorrhizae on spruce (Agerer 1987-1995). Rarely on *Quercus petraeae*. (Wilson, 2003)

Entoloma sinuatum (Bull.: Fr.) Kummer. Mycorrhizal on Salix sp. (= Weide = Willow) Fruitbodies found on weakly acidic soils and found in old growth under beech or beech /oak and also on soils rich in calcium carbonate (Agerer 1987-1995). Rarely mycorrhizal on *Quercus petraeae*. (Wilson, 2003)

Fagirhiza arachoidea . Mycorrhizal on *Fagus sylvatica* Ascomycete in litter layer but no known fruiting body (Agerer 1987-1995). Mycorrhizae seldom present on *Quercus petraeae* (Wilson, 2003).

Fagirhiza cystidiophora. Mycorrhizal on *Fagus sylvatica* . Probably formed by a Tuber species, prefers half rotted beech litter. No known fruiting body. (Agerer 1987-1995). Common *Quercus petraeae* oak mycorrhiza. (Wilson, 2003)

Fagirhiza fusca. Mycorrhizal on *Fagus sylvatica* No known fruiting body. Ectomycorrhizae easily distinguished by dark brown cottony envelope of emanating hyphae. Found on various soil types. (Agerer 1987-1995). Extremely common as *Quercus petraeae* oak mycorrhiza. (Wilson, 2003)

Fagirhiza globulifera. Mycorrhizal on *Fagus sylvatica* . No known fruiting body. Cystidia densely filled with oily droplets. Basidiomycete. Prefers acid humus and mineral soil. Rarely in beech litter. (Agerer 1987-1995). Rarely found as *Quercus petraeae* mycorrhizae. (Wilson, 2003)

Fagirhiza granulosa . Mycorrhizal on *Fagus sylvatica*. No known fruiting body. Probably formed by *Russula fellea*. (Agerer 1987-1995). Common oak *Quercus petraeae* mycorrhiza. (Wilson, 2003)

Fagirhiza setifera. Mycorrhizal on *Fagus sylvatica* No known fruiting body. Prefers litter and humus layers, rarely mineral soil. Characteristic long thickwalled cystidia. (Agerer 1987-1995). Common *Quercus petraeae* oak mycorrhiza. (Wilson, 2003)

Fagirhiza spinulosa. Mycorrhizal on *Fagus sylvatica* No known fruiting body. Prefers humic mineral soil layer, rarely found in humus or litter layer. Characteristic bottle shaped cystidia. (Agerer 1987-1995). Common *Quercus petraeae* oak mycorrhiza. (Wilson, 2003)

Fagirhiza tubulosa. Mycorrhizal on *Fagus sylvatica* No known fruiting body. Prefers half decomposed beech litter. (Agerer 1987-1995). Very common *Quercus petraeae* oak mycorrhiza. (Wilson, 2003)

Genea hispidula Berk. et Br. Mycorrhizal on *Fagus sylvatica* Prefers humic mineral soil, rarely in humus or litter. Characteristic chestnut brown color and thick brown clampless hyphae (Agerer 1987-1995). Very common *Quercus petraeae* mycorrhiza (Wilson, 2003)

Genea verrucosa Vitt. **<u>Mycorrhizal on *Quercus sp*</u>**. (=Eiche=Oak) Found in humus or degraded litter and occasionally dominant in Hungarian oak forests. (Agerer 1987-1995). Common *Quercus petraeae* oak mycorrhiza. (Wilson, 2003)

Gomphidius roseus (Fr.) Karst. . Mycorrhizal on *Pinus silvestris*. (=Kiefer=Pine) Fruiting bodies prefere acid sandy soil. Absent on limed soil. A symbiont of *Suillus bovinus*.. Very similar to *Thelephora terrestris*, besides rosy color distinguished by gelatinized hyphae within the rhizomorphs. (Agerer 1987-1995). Member of Gomphidiaceae (Basidiomycetes) where co-growth of ectomycorrhizae with Boletaceae, Suilloideae and Rhizopogonaceae seems to be a common feature. Anatomical interrelationships of *G. roseus* with *Suillus bovinus* and *Pinus silvestris* common.. This relationship could be symbiotic, parasitic, commensal or opportunistic but since the Gomphidiaceae tend to have more a primative morphology it is highly likely that they are dependant upon Suillus or maybe even parasitic. Brown spores. *Gomphidius glutinosus/Pinus silvestris* mantle autofluorescence: UV filter 340-380 nm; slightly blue, blue filter 450-490 nm: slightly yellow; green filter 530-560 nm: slightly red *Gomphidius roseus* mantle autofluorescence: not studied (Agerer, 1991) Rarely found as *Quercus petraeae* oak mycorrhizae (Wilson, 2003)

Inocybe appendiculata Kühn. Mycorrhizal on *Picea abies*. Fruiting bodies predominantly under conifers but also present under ***Quercus*** and *Carpinus*. (Agerer, 1987-1995). Occasionally present as *Quercus petraeae* oak mycorrhizae. Other species fruiting bodies present (*Incybe fatigiata, I. praetevisa, Inocybe* sp.) (Wilson, 2003).

Inocybe obscurobadia (J. Favre)Grund D.E. Stuntz. Mycorrhizal on *Picea abies*. Fruiting bodies common with *Picea, Abies, Pinus* and rarely deciduous trees (*Alnus, Salix, Populus, **Quercus**, Larix*) on somewhat calcareous soils. (Agerer, 1987-995). Cortinariaceae, Agaricales, Agaricomycetidae, Basidiomyctes, Basidiomycota (CABI, 2002). Occasionally present as *Quercus petraeae* mycorrhizae. (Wilson, 2003)

Laccaria amethystina (Bolt) Murrill (Agerer, 1987-1995); *Laccaria amethystina* (Bolt. Ex Hooker) Murr. (Brand & Agerer, 1986); *L. amethystina* Cooke (1883), *Tremella amethystea* Bull, *L. amethystea* (Bull) Murrill (1914), Hydnangiaceae, Agaricales, Agaricomycetidae, Basidiomycetes, Basidiomycota. 153 *Laccaria* species, 5 variations of *L amethystina*. (CABI Bioscience, 2002) Mycorrhizal on *Fagus sylvatica*. Fruiting bodies prefer acid or calcareous soils of deciduous forests (Agerer, 1987-1995). Autofluorescence of *Laccaria amethystina/Fagus sylvatica* : UV 340-380 mantel and hyphae, light blue, Blue 450-490 greenish orange. (Brand & Agerer, 1983). Occasionally present as *Quercus petraeae* mycorrhizae (Wilson, 2003).

Lactarius acris Bolt.: Fr.(Agerer 1987-1995) *Lactarius acris* (Bolton:Gray) Fr. Or *Agaricus acris* Bolton Russulaceae, Russuales, Agaricomycetidae, Basidiomycetes, Basidiomycota (CABI Bioscience, 2002) Mycorrhizal on *Fagus sylvatica*. (Morphologically very similar to *L. picinus* associated with spruce.) Coralloid mycorrhizal clusters prefer dense, humic clay mineral soil (Ah) under beech litter. Fruiting bodies prefer deciduous woods on limy soil in low to mountainous regions but also found on acid soil. Fruiting bodies also associated with Castanea. (Agerer, 1987-1995). Ectomycorrhiza prefer half decomposed beech litter (Brand, 1989). Rarely to seldom present as *Quercus petraeae* mycorrhizae. (Wilson, 2003)

Lactarius chrysorrheus (Fr.) Fr. **Mycorrhizal on *Quecus robur*** Fruiting bodies found primarily on oligotrophic acid sandy and loam soils, infrequently on lime soils, under deciduous (oak , chestnut) trees but sometimes in mixed forest with conifers. (Agerer, 1987-1995). *Lactarius chrysorrheus* is common in oak woods. The cap exudes a milky juice when broken which turns yellowish when exposed to air. Not edible (Lewington & Streeter, 1993) Autofluorescence of *Lactarius chyrsorrheus/Quercus robur* : UV 340-380 nm: no fluoresence,. except for light stripes visible due to underlying cell fluorescence: Blue 450-490: no fluorescence; green filter (530-560 nm): no fluoresence. (Palfner & Agerer, 1996) Rarely found as mycorrhiza on *Quercus petraeae* oak in both limed and unlimed soil at 0-10 depth. (Wilson, 2003).

Lactarius pallidus Pers. ex Fr. Mycorrhizal on *Fagus sylvatica.* Ectomycorrhiza prefer the deeper humic and humic mineral soil layers and calcareous soils in beech forests. Fruiting bodies are widespread under beech frequently in limestone mountains but in some cases also on acidic soils (Agerer, 1987-1995). Rarely to occasionally found on *Quercus petraea* roots in the spring (Wilson, 2003).

Lactarius porninsis Roll. Mycorrhizal on *Larix decidua*. Fruiting bodies found on all soil types up to 2250 m elevation in mountain-subalpine environments. (Agerer, 1987-1995). Rarely present as *Quercus petraeae* mycorrhizae. (Wilson, 2003).

Lactarius rubrocinctus Fr. Mycorrhizal on *Fagus sylvatica*. Ectomycorrhiza infrequently found in beech forests in dense humic clay soil under thin litter layer, along paths. Like *L. subdulcis,* this mycorrhiza is often infected with and endotrophic ascomycete. Fruiting bodies are infrequent but may be present on limy basalt or clay soil with high nutrient levels in beech woods. (Agerer, 1987-1995). Absent in the unlimed oak forest and rarely present as *Quercus petraeae* mycorrhiza in shallow limed soil. (Wilson, 2003).

Lactarius subdulcis Bull.: Fr. Six species variations (CABI Bioscience 2002). Mycorrhizal on *Fagus sylvatica* . Ectomycorrhiza prefer half decomposed beech litter (Brand, 1989). Fruitbodies acidophilus, prefering weakly acidic or weakly basic moist soils with a thick litter layer over top (Agerer, 1987-1995Voiry (1981) found the fruitbodies of *Lactarius subdulcis* near characteristic **mycorrhizae on Oak** and beech and also found the fruitbodies of related species *L. blennius* and *L. volemus* in the vicinity. Extremely common in unlimed. *Lactarius subdulcis* can also be mycorrhizal on *Pinus sylvestris* in artificial cultures). Autofluorescence of *Lactarius subdulcis/Fagus sylvatica* : UV, 340-380nm = whitish cream mantle, Blue filter 450-490 nm: greenish orange to greenish yellow. (Brand & Agerer, 1986). (Pachlewski & Pachlewska, 1974). *Quercus petraea* forest as mycorrhizae, less common in limed areas (Wilson, 2003).

Lactarius vellereus (Fr.) Fr. Mycorrhizal on *Fagus sylvatica*. Fruiting bodies prefering highly acidic (pH 3.7-5.0), but occuring on acidic (pH 5.0-5.5), weakly acidic and weakly alkaline moist soils (Agerer, 1987-1995). Autofluorescence of *Lactarius vellereus/Fagus sylvatica* : UV filter 340-380 nm = inner mantle pale blue, middle mantle layer olive-yellow, outer mantle bright light blue; Blue filter 450-490 nm = mantle greenish-yellow middle mantle somewhat more greenish-orange. (Brand & Agerer, 1986) Luppi & Gautero (1967) found *Lactarius vellereus* **mycorrhizal on oak** along with their corresponding fruiting bodies. Rarely found in unlimed, and occasionally found on limed soils as *Quercus petraea* mycorrhizae (Wilson 2003).

Paxillus involutus (Batsch) Fr. Basionym = *Agricus involutus* Batsch. Paxilliaceae, Boletales, Agricomycetidae, Basidiomyctes, Basidiomycota. Seven species variations known. (CABI Bioscience, 2002). Mycorrhizal on *Picea abies.* (Agerer 1987-1995). *Paxillus involutus* (Brown roll-rim) common in broadleaf forests on acid soils especially under oak and birches. Poisonous. (Lewington & Streeter, 1993) Fruting bodies prefer acid to sub acidic soils in deciduous forests, with a pH range of 4.0 to 8.2 in sandy, silicate to loamy soils and in beech forests prefering humus layers with low metal ion concentration but high organic matter content (0-5 cm depth) (Agerer 1987-1995). Hönig et al (2000) found several genetic isolates of *Paxillus involutus* variously successful in artificial innoculation trials forming fruiting bodies and **mycorrhizal associations with oak** and beech. *Quercus petraea / Paxillus involutus* mycorrhizae are very common on unlimed soil, very rare on limed soils at 0-10 cm depth (Wilson, 2003)

Phellodon niger (Fr.:Fr.) Karst. Mycorrhizal on *Picea abies*. Mycorrhizae are most common in mineral soil layer. Fruiting bodies found under Norway spruce in mountainous regions on acid sandy soils often over calcareous bedrock and under a thin litter layer but have been found on black, peaty somewhat limy humus. (Agerer 1987-1995). Quercus petraea mycorrhiza were occasionally found, year round in unlimed soil, and in the fall only in the limed soil at 0-10 cm depth (Wilson, 2003).

Piceirhiza bicolorata . Mycorrhizal on *Picea abies* , root seems to penetrate the fungal mantle and then become quickly reinfected by a young fungal mantle (Agerer, 1987-1995). Common in the spring, rare in the fall in moist soil on unlimed oak roots, and rarely present in the fall on limed *Quercus petraea* roots. (Wilson, 2003).

Piceirhiza chordata. Mycorrhizal on *Picea abies* (Agerer, 1987-1995). Extemely common especially in moist soil as *Quercus petraea* mycorrhizae, thin brownish mantle confirmed by microscopic cryosections (Wilson, 2003).

Piceirhiza gelatinosa. Mycorrhizal on *Picea abies (*Agerer, 1987-1995). Seldom found on moist unlimed soil, rare on moist limed soil as *Quercus petraea* mycorrhizae (Wilson, 2003).

Piceirhiza glutinosa = Elaphomyces sp. (Rothe, 1999 pc). Mycorrhizal on *Picea abies* (Agerer 1987-1995). Present occasionally in moist unlimed soil spring and fall, and on limed soil in dry spring and and rarely in moist fall soil as *Quercus petraea* mycorrhizae (Wilson, 2003).

Piceirhiza guttata. Mycorrhizal on *Picea abies* (Agerer, 1987-1995). Rarely present in moist unlimed soil (S&F), rarely present in limed soil but more often seen in moist rather than dry fall soil as *Quercus petraea* mycorrhiza (Wilson, 2003).

Piceirhiza nigra. Mycorrhizal on *Picea abies* (Agerer, 1987-1995). Common in moist unlimed soil, slightly more common in limed soil in dry spring and wet fall as *Quercus petraea* mycorrhizae (Wilson, 2003).

Piloderma croceum Erikss. & Hjortst. Mycorrhizal on *Fagus sylvatica*. Mycorrhizae prefer acid humus, very rare in beech woods in Central Europe, but frequent in beechwoods in Northern Europe. Mycorrhiza is easily recognized by its bright yellow color, corticrocin grains and needle-shaped crystals and clampless hyphae. Fruiting bodies distribution mainly in northern conifer woods on acid soil. (Agerer 1987-1995). Mycorrhiza were absent from oak roots in unlimed soil and rarely present on *Quercus petraea* only in the moist limed soil at 0-10 cm depth (Wilson, 2003)

Pinirhiza rufomaculata. Mycorrhizal on *Pinus sylvestris* L. Mycorrhiza found in mineral soil layer, easily distinguished by the reddish starlike arrangement of cells in middle and inner mantles which gives patchy appearance (Agerer, 1987-1995). Very very rare and only seen one fall on moist limed soil (0-10 cm depth) as *Quercus petraea* mycorrhiza. Probably an accidental species. (Wilson, 2003).

Pisolithus tinctorius (Mich.: Pers.) Coker & Couch. Mycorrhizal on *Picea abies*. Fruitbodies form on poor sandy soil, often on mining wastes of brown coal, black anthracite, slate and kaolin (Agerer 1987-1995). Absent from unlimed soil, and very, very rarely present on limed soil in the fall as *Quercus petraea* mycorrhiza. Probably an accidental species. (Wilson, 2003).

Pseudotomentella tristis (P. Karst.) M. J. Larsen. Mycorrhizal on *Salix herbacea* L. Fruitbodies mostly found on deciduous wood mainly on decayed branches, and trunks. (Agerer, 1987-1995). Thelephoraceae family, 22 related speces. (CABI Bioscience, 2002). Rare on unlimed sol, common on limed soil only during moist fall as *Quecus petraea* mycorrhiza (Wilson, 2003).

Quercirhiza fibulocystidiata. **Mycorrhizal on *Quercus* sp**. Found in sandy soil of mixed deciduous forest at 250-300 m elevation, Central Hungary (Agerer, 1987-1995). Common in moist soil as *Quercus petraea* mycorrhiza, more abundant in limed than unlimed soil (Wilson, 2003).

Quercirhiza squamosa. **Mycorrhial on *Quercus robur* L.** (Agerer 1987-1995). **Mycorrhizal on *Quercus robur*** with other similar brown mycorrhizae found on *Fagus sylvatica* and *Picea abies*. Autofluorescence: of *Quercirhiza squamosa / Quercus robur*:

254, 366, 340-380 (UV), 450-490 (Blue), 530-560 (Green) nm - no fluorescence in whole mantle or sections. (Palfner & Agerer, 1996). Extremely abundant in unlimed soil especially during moist spring, less frequent in limed soil primarily present in spring as *Quercus petraea* mycorrhizae (Wilson, 2003).

Quecirhiza sublutea. **Mycorrhizal on *Quercus ilex* L.** Mycorrhiza found in superficial soil down to 10 cm with a humic pH of 8.0-8.5. (Agerer, 1987-1995). Occasionally found as *Quercus petraea* mycorrhiza in more often in moist unlimed soil than in limed soil (Wilson, 2003).

Russula acrifolia Romagn. Mycorrhizal on *Picea abies*. Fruiting bodies on a variety of soils from acidic (pH 4.0) to subacidic (pH 6.5) to neutral (pH 7) which are moist and nutrient rich and overlay sandstone or shell-lime soils or rarely over rhyolith (Agerer 1987-1995). Autofluorescence of *Russula acrifolia/Picea abies*: UV filter 340-380 nm: greenish-blue, cystidia and inner mantle layers more intense than middle mantle; Blue filter 450-490 nm: yellow, zonation as above; Green filter 530-560 nm: red, zonation as above (Agerer et al, 1994). Rare in moist unlimed soil, but very common in limed soil in dry spring and moist spring & fall as *Quercus petraea* mycorrhizae (Wilson, 2003).

Russula firmula J. Schff. Mycorrhizal on *Pinus mugo* Turra. According to the literature review in Agerer (1987-1995), fruiting bodies appear in coniferous forests (*Picea abies, Pinus mugo*) from colline to subalpine regions (600 m - 1430 m - 1900 m elevation), almost always on neutral to calcareous soils, but may also be present in deciduous forest. (Agerer, 1987-1995). As *Quercus petraea* mycorrhizae, it was only rarely present in very moist fall weather in both the limed and unlimed plot. (Wilson, 2003).

Russula fuegiana Singer. Mycorrhizal on *Nothofagus pumilio* (Poepp.et Endl.) Krasser in South America (Agerer, 1987-1995). Unlikely to be the same species, but a very similar mycorrhiza was rarely found in association with *Quercus petraea* in moist fall soil, slightly more common in the unlimed than limed plot (Wilson, 2003).

Russula illota Romagn. Mycorrhizal on *Fagus sylvatica*. Mycorrhizae preferably growing in mineral humic clay, agglutinated with mineral particles. Fruiting bodies found in deciduous and coniferous forest on acid, slightly acid, neutral and calcareous soils on clay and limestone soil. (Agerer, 1987-1995). Absent in the unlimed plot, rarely present as *Quercus petraea* mycorrhizae in very moist fall weather in the limed plot. (Wilson, 2003).

Russula mairei Sing. Mycorrhizal on *Fagus sylvatica*. Mycorrhiza found in beech litter as well as in humus layers and humic mineral soil. Fruiting bodies found in beech forest on calcareous, neutral and rarely acidic soils. (Agerer, 1987-1995). Very rarely present as *Quercus petraea* mycorrhizae and then only in very moist soil (Wilson, 2003).

Russula ochroleuca (Pers.) Fr. Mycorrhizal on *Picea abies*.(Brand & Agerer, 1986) Ectomycorrhiza also associated with *Abies alba, Betual pendula, Carprinus betulus, Fagus sylvatica, Larix decidua, Picea abies, Pinus sylvestris* and ***Quercus robur*** (Pillukat & Agerer, 1991 Fruiting bodies most frequently on weakly acidic (pH 6.0-6.5) or decalcified soil (Agerer, 1987-1995). *Russula ochroleuca* is a well known mycorrhizal fungus abundant in both coniferous and deciduous woodlands throughout Europe that forms fruiting bodies in late summer and fall. Edible. (Lewington & Streeter, 1993). Autofluorescence *of Russula ochroleuca / Abies alba* UV filter 340-380 nm: outer mantle light greenish yellow, inner mantle bluish white; Blue filter (450-490 nm) outer mantle intense yellow, inner mantle bluish white; Green filter (530-560 nm) light red. (Pillukat & Agerer, 1991). Autofluorescence of *Russula ochroleuca/ Picea abies* varies somewhat: UV filter (340-380 nm) slightly yellowish gree; Blue filter (450-490): distinctly yellowish green (Agerer, 1986). The pigment Russupteridine-yellow V isolated from young *Russula ochroleuca* by Gill & Steglich (1987) may account for some of the greenish yellow fluorescence in UV light (Pillukat & Agerer, 1991). The characteristic yellow pigment dots are not conspicious or absent on older parts (Agerer, 1986) Abundant on unlimed soil , occasionally present on moist limed soil in the fall as *Quercus petraeae* mycorrhizae. (Wilson, 2003)

Tetraberliniaerhiza sp. (bicolor?) Mycorrhizal on *Tetraberlinia bifoliata* (Harms) Hauman from Korup National Park rain forest, Cameroon (Agerer, 1987-1995). Highly unlikely that this is a correct identification, although no other species is as close in gross morphology, so it will be considered an unknown morphotype α *Tetraberliniaerhiza* sp. Very rarely found in the fall on limed soil as a *Quecus petraea* mycorrhiza (Wilson, 2003).

Tomentella albomarginata (Bourd. & Galz) M. J. Larsen. Mycorrhizal on *Pinus sylvestris*. Fruiting bodies on well decayed coniferous and deciduous wood. (Agerer, 1987-1995). Extremely rare, found only in moist fall on limed soil as questionable *Quercus petraea* mycorrhiza (Wilson, 2003).

Tomentella ferruginea (Pers.)Pat. Mycorrhizal on *Fagus sylvatica*. Found in mixed stands of *Fagus sylvatica* and *Picea abies* in acid humus under litter. Fruiting bodies very common with world wide distribution, on well decayed deciduous and coniferous wood. (Agerer, 1987-1995). Very common on unlimed soil in dry and moist fall weather, more common on limed soil in dry spring and moist fall weather as *Quercus petraea* mycorrhiza (Wilson, 2003).

Tuber aestivum Vitt. Mycorrhizal on *Corylus avellana* L. (Agerer, 1987-1995). Very rare on both limed and unlimed soil in moist fall weather as *Quercus petraea* mycorrhizae (Wilson, 2003)

Tuber melanosporum Vitt. Mycorrhizal on *Corylus avellana* L. Fruitbodies in calcareous, sunny regions in association with broad leaf trees, seldom with needle trees, mainly in humus or soil layers of oak forests with soils containing calcareous flint (Agerer, 1987-1995). Very common in unlimed soil in dry spring, less so in dry fall and rare in wet seasons, absent in limed soil, occasionally in wet fall as *Quercus petraea* mycorrhiza (Wilson, 2003).

Tuber mesentericum Vitt. Mycorrhizal on *Corylus avellana* L. Fruitbodies in loose calcareous soil under *Quercus* and *Ostrya carpinifolia.* Associated with many broadleaf or needle trees (Agerer, 1987-1995). Absent on unlimed soil, rarely present on limed soil as *Quercus petraea* mycorrhiza (Wilson, 2003).

Tuber puberulum Berk. & Br. . Mycorrhizal on *Picea abies*. Fruiting bodies in deciduous forests in the top organic layer of sandy soil, more often in microniches of decaying bark of Norway spruce, logging waste piles (pH 5.9) and beneath litter layer of young stands of Norway spruce on limestone. (Agerer, 1987-1995).
Absent to rare on unlimed soil, occasionally present on limed soil as *Quercus petraea* mycorrhiza (Wilson, 2003).

Tuber rufum Pico. Mycorrhizal on *Corylus avellana* L. Fruiting bodies are found in calcareous soils with many different deciduous (sandy oak and mixed forest in colline areas) and coniferous trees. (Agerer, 1987-1995). In the unlimed forest, *Tuber rufum/Quercus petraea* mycorrhiza were extremely common in dry spring and fall, nearly dissappearing in wet seasons while in the limed forest they were occasionally found in the dry spring, disappearing in the dry fall and rarely found in the wet seasons (Wilson, 2003).

Xerocomus badius (Fr.) Kühner: Gilbert. (Syn: *Boletus badius* Fr.) with 5 varianta (CABI, Bioscience 2002). Mycorrhizal on *Picea abies*. Fruitbodies prefer more or less acid soils of various types, preferably in coniferous forest with scanty herbaceous layer (Agerer, 1987-1995). The *Xerocomus badius / Quercus mycorrhizae* were very common on unlimed soil in dry spring weather but dissappearing after a severely dry fall and infrequently present only during the dry fall on limed soil (Wilson, 2003).

Xerocomus chrysenteron (Bull.) Quél. (Basionym *Xerocomus chrysenteron* (Bull.:St. Amans) Quél (Hofman, 1989). (Syn. Boletus chrysenteron Bull) with 10 variants (CABI Bioscience 2002). May be confused with Xerocomus pruinatus (Fr.)Quél. (pc Haesse, 2002). Mycorrhizal on *Fagus sylvatica*. Ectomycorrhiza very common on beech in the litter layer but with large coralloid clusters in deeper humus (Oh, Ah) layers. Fruiting bodies prefer deciduous forests. *Xerocomus chysenteron var. acidophilus* prefer pH 3.7-4.8 (5.0) soils, while the typical form is rather indifferent, on soils pH (5.0-8.2). In Beech forests, fruiting bodies are slightly positively related to Phospahte in the litter and negatively related to Nitrogen content in the humus layer although rather indifferent to metal ion saturation as well as organic matter content. (Agerer, 1987-1995). *Xerocomus chrysenteron / Fagus sylvatica* Autofluorescence : UV filter 340-380 nm: mantle is nonfluoresent, rhizomorphs pale ochre with pale bluish central hyphae. (Brand, 1989) *The Xerocomus chrysenteron / Quercus petraea* mycorrhizae were very common in unlimed moist soil and occasionally present in limed moist soil (Wilson, 2003).

Xerocomus subtomentosus (L.: Fr.) Quél. (Syn.: *Boletus subtomentosus*) with 11 variants (CABI Bioscience 2002) Anatomically similar to *Xerocomus armeniacus* (Palfner & Agerer, 1995). **Mycorrhizal on *Quercus suber*** and *Castanea sativa* (Palfner & Agerer, 1995), **Mycorrhizal on *Quercus robur.*** Fruiting bodies found on highly to weakly acidic soils in coniferous and deciduous forests in lowlands and mountains (Agerer, 1987-1995). *Xerocomus submentosus / Quercus robur* and *Xerocomus armeniacus / Quercus robur* Autofluorescence: UV filter 340-380 nm: mantle cells singly, or in groups whitish-light blue; Blue filter 450-490 nm: the same cells yellowish white or yellowbrown; Green filter 530-360 nm- non fluorescent. (Palfner & Agerer, 1995). *Xerocomus chrysenteron / Quercus petraea* mycorrhiza were very rarely found in mois soil in both the unlimed and limed forest. (Wilson, 2003)

Fagus sylvatica Mycorrhizae NOT FOUND on Merzablen oak

Cortinarius cinnabarinus Fr. (Agerer 1987-1995)

Fagirhiza vermiculiformis (Agerer 1987-1995)

Fagirhiza oleifera (similar to *Piceirhiza oleifera*)(Waller et al, 1993)

Geastrum fimbriatum (Agerer 1987-1995)

Tricholoma acerbum (Bull.: Fr) Quél (Waller & Agerer, 1993; Agerer 1987-1995)

Tricholoma sciodes (Secr.) Mart. (Agerer, 1987-1995)

[Tylopilus felleus (Bull.) Karst. Fruiting bodies (Agerer, 1987-1995).]

Quercus sp. Mycorrhizae NOT FOUND on Merzalben Oak

Amanita phalloides. Ectomycorrhizal with Quercus sp. (Schütt et al, 1992, p. 306). Fruiting bodies of other Amanita species (*Amanita citrina, A. citrina var, A.eliae, A. eliae var. A. patherina, A. rubsecens*) found in the Merzablen oak forest (Wilson, 2003).

Collybia dryophila (Russet Shank) a common toadstool of mixed broadleaf and oak woodlands across Europe which grows on leaf litter and soil but probably forms mycorrhizal associations. Spring to fall. Not edible. (Lewington & Streeter, 1993) Other fruiting bodies (*Collybia butyracea, C.erthropus C. kuehneriana*) were present in the Merzablen oak forest (Wilson 2003).

Lactarius serifluus DC.: Fr. Mycorrhizal on *Quercus robur*L. and *Castanea sativa* (Palfner & Agerer, 1996).

Lactarius quietus (Oak Milk Cap) is a common autumn fruiting body in acidic oak woods with strong mycorrhizal associations. Not edible. (Lewington & Streeter, 1993)

Leccinum quercinum, ectomycorrhizal on Quecus sp. (Schütt et al, 1992, p. 306). a member of the Boletaceae family that readily forms mycorrhizal associations, uncommonly found as a fruiting body in autumn. Edible. (Lewington & Streeter, 1993)

Lycophyllum decastes (Fr.) Sing. Mycorrhizal on *Quercus robur* L. Fruiting mainly in disturbed areas - roads, paths, waste places, old sawdust piles, in woods. (Agerer 1987-1995).

Polyporoletus sublividus Snell. Mycorrhizal on *Abies amabilis* Forb.occuring in the Pacific Northwest of North America in higher mountain to subalpine coniferous forest. It is disjunct in North America, originally found in oak-pine woods in Tennessee. (Agerer 1987-1995). Not likely a possiblity here in Germany.

Populirhiza pustulosa . Mycorrhizal on *Populus tremula* L. Ectomycorrhiza found in the acidic mineral soil of a *Pino-Quercetum* forest with the same morphotype on a *Pinus sylvestris* root. (Agerer, 1987-1995).

Ramaria subbotrytris (Coker) Corner. Mycorrhizal on *Quercus robur* L. Fruiting bodies in deciduous forests primarily under beech and oak, but also found in conidersous woods with silver fir. (Agerer, 1987-1995).

Suillus luteus, ectomycorrhizal on Quercus sp. (Schütt et al, 1992, p 306) particularily *Quercus pausidentata* (Masui, 1926)

Tricholoma acerbum (Bull.: Fr.) Quél. Mycorrhizal on *Fagus sylvatica.* Fruiting bodies found under beech and oak. Indifferent regarding soil acidity, found in highly acidic (pH 3.8-5.0) to neutral (pH 4.8-7.3) soils and on limy and loamy soils. (Agerer, 1987-1995).

Other Fruiting bodies associated with oak in the literature

Collybia fusipes (Spindle Shank) often appear as fruiting bodies at the bases of oaks and beeches across Britain and most of mainland Europe from spring to fall. They are not edible. (Lewington & Streeter, 1993) Fruiting bodies (*Collybia butyracea, C.erthropus C. kuehneriana*) were present in the Merzablen oak forest. (Wilson, 2003).

Russula atropurpurea (Black-purple russula) is a very common fungus growing in groups especially in oak forests in Europe in late summer and fall. Not edible. (Lewington & Streeter, 1993). Fruiting bodies present in Merzablen. (Wilson, 2003)

Hebeloma species *H. edurum* Metr. Mycorrhizal on *Larix decidua* but fruitbodies found on high elevation calacarious coniferous forest soils and sometimes under *Fagus sylvaticus* (Agerer 1987-1995). *Hebeloma radicosum* (HY-1Hn) is a basidiomycete ectomycorrhiza that can live independantly from its possible *Fagaceae* or *Betulaceae* hosts probably because of its ability to use available starch (Ohta, 1998) Both are ectomycorrhizal fungi but neither species was found in the oak forest although other Hebeloma species fruiting bodies (*H. austuliniforme & H. strosphosa*) were present. Related mycorrhiza not found. (Wilson, 2003)

Oak Pathogens in the literature

Microsphaera alphitoides (Oak mildew) is a serious disease of oak foliage in N. Europe especially on young trees in frequently cut coppices. (Lewington & Streeter, 1993)

Oak Saprophytes in the literature

Bulgaria inquinans (Black bulgar) a discomycete cup fungus appears on dead wood of oak and other broadleaf trees in the autumn and winter. (Lewington & Streeter, 1993)

Chlorociboria aeruginascens (Green wood cup or Green oak) is saprophytic on several broadleaf trees but espcially oak characterized by a green residual staining (Lewington & Streeter, 1993)

Calocera cornea & *Calcocera glossoides* appear in late summer and autumn on dead wood in groups of yellow gelatinous sprouts. (Lewington & Streeter, 1993)

Mycena inclinata is saprophytic on stumps and trunks of dead oaks appearing in late summer and autumn throughout Britain and Europe. Not edible. (Lewington & Streeter, 1993)

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Appendix 2: Merzalben Mushroom Fruiting Body Collection

Purpose:

The purpose of the following information was to determine the prevalence of mushroom fruiting bodies in the Merzalben Research site with the idea of comparing the surface findings to the subterranean mycorrhizal species distributions as an indirect means of confirming mycorrhizal species identifications.

Methods:

Fruiting bodies were collected on October 2, 9, 16, 23 of 2000 for one hour each day and on October 10 and 17 of 2001 for 2 hours each day. One or two representative samples of each observed species was obtained from both the unlimed and limed forest areas. The relative abundance of each individual species was noted. The samples were stored on ice in plastic bags during transport were identified within 48 hours upon return to the lab. Identifications were made and confirmed using several sources (Phillips, 1998; Person, 1997; Hausner, 1996; Hagara, 1995; Gerhardt, 1995; Flück, 1995; Courtecuisse & Duhem, 1993; Lewington & Streeter, 1993; Pacioni, 1981). The best samples were photographed. Where possible, the fungi were air or oven dried and stored in glass containers in a cool (10 °C) dark room. Some samples were too large and moist for drying and so they were frozen or just photographed.

Results:

Appendix 2A : Summary of species found and their abundance for both unlimed and limed forest zones. Prevalence of fruiting bodies did not directly or indirectly correspond to the prevalence of mycorrhizal species.

Appendix 2B: Nomenclature for each species.

Appendix 2C: Habitat notes for each species (Demographic notes also are here).

Appendix 2D: Dendrology notes (Class, Order, Family)

Appendix 2E: Dendrology notes (Tribe, Section) & References used for Identification

Discussion:

The majority of fruiting bodies found were basidiomycetes. (The majority of ectomycorrhizae are also basidiomycetes). During the dry fall of 2000, the fruiting body harvest was extremely sparse but during the wet fall of 2002, the harvest was abundant and diverse. In a similar fashion, the mycorrhizae also were sparse in 2000 but abundant in 2001. It was hoped that there would be more correlation between the fruiting structures and the subterranean mycorrhizae but that did not occur. Only 20 of the 128 different species of fruiting fungi collected were known to be mycorrhizal (Appendix 2E). Approximately 60 species of mycorrhizae were collected at the same time (49 which were positively identified were included in this study). Of the 35 mycorrhizae that occasionally are known to form fruiting bodies (including 5 *Tuber* sp.) (Appendix 1) only 10 (***Boletus edulis, Cortinarius sp., Laccaria amethystina, Lactarius chrysorrheus, Lactarius pallidus, Lactarius subdulcis, Paxillus involutus, Russula ochroleuca, Xerocomus badius,*** and ***Xerocomus chrysenteron***) were represented by fruiting structures in the Merzalben forest study area. In some respects this is not a bad correlation since it at least confirms that those mycorrhizae should be present in the forest under study. It is well known that mycorrhizae predominance cannot always be correlated to surface fruiting distribution (Cripps, 2001) (See Section A1-3-3) *Lacccaria amethystina* and *Russula ochroleuca* were common on both plots both in the dry and wet falls while *Boletus edulis* only appeared in the wet fall in both zones. What is perhaps of more interest is the fact that the majority of the above species appeared during the dry fall rather than the wet fall. *Lacccaria amethystina, Lactarius subdulcis, Russula ochroleuca* and *Xerocomus badius* were found in both zones while *Lactarius chrysorrheus, Paxillus involutus* and *Xerocomus chrysenteron* were found only in the unlimed forest area. This would imply that under stress, mycorrhizae seek other means of ensuring survival, such as the formation of fruiting structures. It might also imply that the mycorrhizae in the unlimed forest soils were more “stressed”. Or, can it be stated that they had more energy reserves and so were able to produce fruits ? Or, are both strategies operating ? The significance of these findings is marred by the fact that the limed study plot was only 60 square meters in size, the sampling time was limited, and the fruiting structures could not be traced directly to ectomycorrhizae on the oak roots.

Conclusions:

When certain mycorrhizal species (*Cortinarius sp., Lactarius chrysorrheus, Lactarius pallidus, Lactarius subdulcis, Paxillus involutus, Xerocomus badius, and Xerocomus chrysenteron)* are under desiccation stress, more fruiting bodies tend to appear. Fruiting bodies for 10 of the 35 possible mycorrhizal species were present in the Merzalben forest.

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Appendix 2A: Merzalben Mushroom Fruiting Body Collection - October 2000 & 2001

Key at end of Appendix 2A	Limed Soil		Unlimed Soil	
Genus species	**Fall 2000**	**Fall 2001**	**Fall 2000**	**Fall 2001**
Agaricus langei			n	
Agaricus silvaticus				nn
Agrocybe pusiola				n
Amanita citrina	k		nnn	n
Amanita eliae				nn
Amanita eliae var.				nn
Amanita pantherina				n
Amanita rubescens	k		n	nn
Armillaria bulbosa ?				n
Armillaria mellea				nn
Armillaria ostoyae		kkk		nnn
Armillaria ostoyae var.				n
Armillaria ostoyae var. Malformed				n
Bisporella citrina	kk		n	n
Boletus edulis		kkkk		nn
Boletus erythropus	k			nn
Boletus impolitus		kkk		nn
Boletus porosporus	kk			
Callistorporium olivascens				n
Calocybe gambosa			n	
Calvatia cinerea	k			
Calvatia excipuliformis	k			
Cariola versicolor		kk		
Cineromyces linbladii		k		
Clinocybe infundibuliformis			n	
Clitocybe graminocola		k		
Collybia butyracea		k	n	
Collybia erthropus		k		
Collybia kuehneriana		k		
Conocybe subovalis/C. brunneola				n
Coriolus versicolor			n	
Cortinarius pallustris				n
Cortinarius pilodeus				n
Cortinarius sp.	k			
Daedalea quercina		k		
Diatrype disciformis	kk			
Entoloma porphyrophaeum			n	
Entoloma rhodopolium var		kkk		
Gleophyllum oebratum		k		
Grifola umbellata		kk		
Hebeloma austuliniforme			n	
Hebeloma strosphosa			n	
Hydropus atramentosus	kk			
Hygrocybe psittacina		k		n

Appendix 2A: Merzalben Mushroom Fruiting Body Collection - October 2000 & 2001

Key at end of Appendix 2A	Limed Soil		Unlimed Soil	
Genus species	**Fall 2000**	**Fall 2001**	**Fall 2000**	**Fall 2001**
Hypholoma capnoides		k		n
Hypholoma fasiculare	kkkk	kkkk	nnn	nnn
Hypholoma sublateritium			n	
Hypochnicium vellereum		k		
Inocybe fatigiata	k			
Inocybe praetervisa			n	
Inocybe sp.	k		n	
Lacatarius quietus				nn
Laccaria amethystina	kkk	kk	nn	nnn
Laccaria bicolor		kk		n
Laccaria laccata	kkk			
Laccaria tortilis				n
Lachnellula subtissima		kk		
Lactarius blennius			n	
Lactarius chrysorrheus			n	
Lactarius deterimus			nn	
Lactarius helvis	k			
Lactarius pallidus		k		
Lactarius quietus	kk		n	nn
Lactarius rufus			nnn	
Lactarius sp	kkk	k	n	
Lactarius subdulcis	k		n	
Lactarius volemus	k			
Lepiota mastoidea	k			
Lepiota rhacodes var. Bohemia				n
Lepiota sp.	k			
Lepista nuda			nn	
Lepista sordida var. Aiathina	kk			
Leucocortinarius bulbiger				n
Lycoperdon perlatum	kk	k		
Macrolepiota mastoidea		kkk		nnn
Macrolepiota procera		kk		n
Marasmius androsaceus			nn	n
Marasmus coharens				n
Melanolauca ingrata?				n
Merulius tremalosus blass form		k		
Mycena aetites			n	
Mycena filopes		k		
Mycena galericulata	k		n	n
Mycena inclinata				n
Mycena lactea		k		
Mycena leucogala	k	kk		nn
Mycena pura		kkk		nn
Mycena rosella	kk			
Mycena sepia	kk			

Appendix 2A: Merzalben Mushroom Fruiting Body Collection - October 2000 & 2001

Key at end of Appendix 2A

	Limed Soil		Unlimed Soil	
Genus species	**Fall 2000**	**Fall 2001**	**Fall 2000**	**Fall 2001**
Mycena sp. (niveipes)		k		
Mycena speirea		k		
Mycena uracea		k		
Myxomphalina maura			n	
Oudemansiella pudens	k			
Panaelus fimicola	k			
Panaeolus alter		k		
Panaeolus campanulatus		k		
Panneolus sp.		k		
Paxillus involutus			n	nn
Paxillus involutus var. Atrotomentosus				nn
Pluteus diettrichii =P.rimulosus				n
Psathyrella atrolaminata	k			
Psathyrella hydrophila var.				n
Psathyrella sp.				nn
Psathyrella spadicea		kk		nn
Ramaria pallida			n	
Russula albonigra var. Pseudonigricans				nn
Russula brunnoviolacea				nn
Russula fella			n	
Russula kromboholzii		k		
Russula luteotacta			n	
Russula orcheoleuca	k	kkkk	nnn	nnnn
Russula queleti	k		n	
Scleroderma			n	
Scleroderma aerolatum			nn	
Scleroderma citrinum	k			
Stereum rugosum		k		
Trichologlossum hirsutum		k		
Tricholoma fulvum				nn
Tricholoma sulphureum	kkk			
Tricholoma sulphureum var.	k			
Tricholoma terreum				n
Tyromyces albellus				n
Xerocomus badius	kkk		nn	
Xerocomus chrysenteron			n	
Xerocomus parasiticus				
Xylaria hypoxylon	kk	kkk		
Xylaria longipes	kk			
Total number of species	39	44	39	51

Key for Appendix 2A:
k or n = few fruiting bodies on limed (k) or unlimed (n) soils
kk or nn = fruiting bodies more common
kkk or nnn = fruiting bodies very common

Appendix 2B: Merzablen Mushroom Fruiting Body Collection - Nomenclature

Genus species	Authors	Alternate names	Common Names
Agaricus langei	(Moeller) Moeller		Großer Waldegerling
Agaricus silvaticus	Schaeff.ex. Secr./ Sch.Fr.		Echter Waldchampignon
Agrocybe pusiola	(Fr.Fr.)Heim		
Amanita citrina	(Schaeff.)S.F.Gray	A.mappa	Gelber Knollenblätterpilz
Amanita citrina var.	(Gillet) Gilbert / (Sch:Fr.)SF Gray	var. Alba	Gelber Knollenblätterpilz
Amanita eliae	Quelet		
Amanita eliae var.			
Amanita pantherina	(DeCand:Fr)Krombholz		Panther cap
Amanita rubescens	(Pers.ex Fr) S.F. Gray		Perlpilz,Blusher
Armillaria bulbosa var.	Marxmueller & Romagnesi	A.gallica=A.lutea	Honey Fungus
Armillaria mellea	(Vahl.ex Fr.) Kummer	Clitocybe mellea	Hallimasch,Honey Fungus
Armillaria ostoyae	(Romagn)Herink	A. obscura	Honey Fungus
Armillaria ostoyae var.			
Armillaria ostoyae var. Mal.		variation -malformed	
Bisporella citrina	(Batschh ex Fr.) Korf & Carp.		
Boletus edulis	Bull.ex Fr.		Penny Bun, Cep, Steinpilz
Boletus erythropus	(Fr. ex Fr.) Secr. /Pers.		Flockenstieliger Hexenröhrling
Boletus impolitus	Fr.		Fahler Röhrling
Boletus porosporus	(Imler) Walt		Gefelderter Röhrling
Callistorporium olivascens	(Boudier) Bon		
Calocybe gambosa	(Fr:Fr)Singer ex Donk	Tricholoma georgii	St. George's mushroom
Calvatia cinerea			
Calvatia excipuliformis	(Pers.) Perd./(Scop.Pers.)Perdeck	Lycoperdon saccatum	Beutel-Stäubling (Handkea ex.)
Cariola versicolor	(L:Fr)Lloyd	Trametes versicolor	Bracket fungi
Cineromyces linbladii			
Clinocybe infundibuliformis	(Schaeff.ex Weinm.) Quel./(Pers.Fr)Ku	C. gibba	Ochrebrauner Trichterling
Clitocybe graminocola	Bon		
Collybia butyracea	(Bull.ex Fr.) Kummer		Butterrübling, Butter cap
Collybia erythropus	(Pers.ex Fr) Kummer / Singer	C. kuehneriana	Rotstieliger Rübling
Collybia kuehneriana	C.acervata ss auct=C.marasmioides	Marasmius erythropus	Marasmius bresadolae
Conocybe subovalis	(Kuehner)ex. Kuehner & Watling	Conocybe brunneola	
Coriolus versicolor	(L.ex Fr.)Quel / (L:Fr)Lloyd	Trametes versicolor	Schmetterlingsporling.Bracket
Cortinarius pallustris	(Moser)Nezdominigo	C.sphagnogenus	
Cortinarius pholideus	(Fr.ex Fr.)Fr.	C.pholideus	Schuppiger Dickfuss
Cortinarius sp.		species unknown	
Daedalea quercina	L.ex Fr. / (L:Fr)Fr	Lenzites quercina	Eichenwirrling,Bracket fungi
Diatrype disciformis	(Hoff ex Fr.)		
Entoloma porphyrophaeum	(Fr.) Karsten		Braunroter Roetling
Entoloma rhodopolium var.	(Fr.)Kummer		Niedringer Roetling
Gleophyllum oebratum			
Grifola umbellata	Pers.ex Fr.	Polyporus umbellatus	Eichhase
Hebeloma austuliniforme			
Hebeloma strosphosa			
Hydropus atramentosus	(Kalchbr)Kotlaba & Pouzar		
Hygrocybe psittacina	(Sch.Fr.)Wuensche/(Sch.Fr)Kummer	Parrot Wax Cap	Papageien-Saftling

Appendix 2B: Merzablen Mushroom Fruiting Body Collection - Nomenclature

Genus species	Authors	Alternate names	
Hypholoma capnoides	(Fr.ex Fr.)Kummer		Graublaettriger Schwefelkopf
Hypholoma fasiculare	(Huds ex Fr) Kummer	Naematoloma f., Sulfurtuft	Grünblättriger Schwefelkopf
Hypholoma sublateritium	(Fr.) Quel.	Brickcaps	Ziegelroter Schwefelkopf
Hypochnicium vellereum	(Ell.& Crag.)Parm.		Wolliger Rindenpilz
Inocybe fastigiata	(Schaeff. ex Fr.) Quel. / (Bull:Fr)Kumm	I. rimosa	Kegelige Risspilz
Inocybe praetervisa	Quelet		Knolliger Risspilz
Inocybe sp.		species unknown	
Lactarius quietus	(Fr.)Fr . / (Fr:Fr) Fr.		Eichenmilchling
Laccaria amethystina	(Bull.ex Merat)Murr / (Huds->)Cooke	L.amethystea, Am. Deceiver	Violetter Lacktrichterling
Laccaria bicolor	(Marie)Orton		Zweifarbiger Lachtrichterling
Laccaria laccata	(Scop:Fr)Cooke	Clintocybe laccata	The Deceiver
Laccaria tortilis	(S.F.Gray)Cooke / (Bolt)Cooke		Gedrehter lacktrichterling
Lachnellula subtilissima	(Cke,)Dennis		
Lactarius blennius	(Fr.) Fr / (Fr:Fr)Fr		Graugruener Milchling, Milk Caps
Lactarius chrysorrheus	Fr.		Goldfluessiger Milchling
Lactarius deterrimus	Groeger		Bitterer Milchling
Lactarius helvis	(Fr.)Fr / (Fr:Fr)Fr.	L. helvus	Maggipliz
Lactarius pallidus var.	(Pers:Fr)Fr		Fleischblasser (Blasser) Milchling
Lactarius quietus	(Fr.)Fr		Eichenmilchling
Lactarius rufus	(Scop.ex Fr.) Fr.		Fuchsfarbener Milchling
Lactarius sp.		species unknown	
Lactarius subdulcis	(Pers. ex Fr.) S.F. Gray		Zimtbrauner Milchling
Lactarius volemus	Fr./ (Fr:Fr)Fr.		Milchbraetling
Lepiota mastoidea	(Fr.) Kummer / (Fr:Fr)Singer	Macrolepiota mastoidea	Spitzbuckliger Schrimpilz
Lepiota rhacodes var.	(Vittadini)Singer / (Wich)Bellu & Lanzo	var. Bohemia	Shaggy Parasol
Lepiota sp.		species unknown	
Lepista nuda	(Bull ex Fr.)Cooke	Tricholoma nuda	Violetter Roetelritterling, Blewit
Lepista sordida var.	(Fr.) Sing. / (Bon)Bon	var. Aiathina	Fleischbrauner Roetelritterling
Leucocortinarius bulbiger	(Fr.) Sing. / (Alb.&Schw:Fr)Singer	Cortinellus bulbiger	Knolliger Schleierritterling
Lycoperdon perlatum	Pers. / Pers. Pers.	L.gemmatum	Flaschenstaeubling
Macrolepiota mastoidea	(Fr:Fr)Singer / (Fr.)Kummer	Lepiota mastoidea	Zitzenwarziger Reisenschirmpilz
Macrolepiota procera	(Scop:Fr)Singer		Parasol Mushroom
Marasmius androsaceus	(L:Fr)Fr	Setulipes androsaceus	Horse-hair Fungus
Marasmus coharens	(Pers:Fr)Cooke & Q		
Melanoleuca ingrata var.		variation ?	
Merulius tremalosus	Fr. / Schrad:Fr	blass form	Gallertfleischiger Faeltling,Dry Rot
Mycena aetites	(Fr.) Quelet		Salmiak-Hemling
Mycena filopes	(Bull.ex Fr.) Kummer	M. iodolens	Faediger Helmling
Mycena galericulata	(Scop.ex Fr.)S.F. Gray		Roseblaettriger Helmling
Mycena inclinata	(Fr.) Quelet		Buntstieliger Helmling
Mycena lactea	(Pers.ex Fr.) Kummer		Nadel-Helmling
Mycena leucogala var.	(Cooke)Sacc.	M.galopus var. Nigra	Schwarzer Helmling
Mycena pura	(Pers.ex Fr) Kummer	variable	Rettich Helmling
Mycena rosella	(Fr:Fr)Kummer		
Mycena sepia	Lange		Fichten-Helmling

Appendix 2B: Merzablen Mushroom Fruiting Body Collection - Nomenclature

Genus species	Authors	Alternate names	
Mycena sp. (nivepes)	(Murr.)Murr	sp.Nivepes (fall variety?)	Frühlings Helmling,Spring Helmling
Mycena speirea	(Fr.)Gillet / (Fr:Fr)Gillet		Haarstieliger Helmling
Mycena uracea			
Myxomphalina maura	(Fr.) Hora / (Lasch)Orton	Tephrocybe anthracophila	Kohlennabling
Oudemansiella pudens	(Pers)Pegler & Young	Collybia longipes=Oudemansiella longipes	
Panaelus fimicola	(Pers:Fr) Quelet		
Panaeolus alter	(Lange) Kuehner & Romagnesi ex Bon		Dunkler Duengerling
Panaeolus campanulatus	(Bull ex Fr.) Quel / (L:Fr.) Quelet	P.retirugis (Fr.)Gill	Glockenduengreling
Paneolus sp.			
Paxillus involutus	(Fr.)Fr. / (Batsch:Fr)Fr		Kahler Krempling,Roll-rim
Paxillus involutus var.	(Fr.)Fr./ (Batsch:Fr)Fr	Tapinella atrotomentosus	Samtfusskrempling
Pluteus diettrichii	Bresadola	Pluteus rimulosus	
Psathyrella atrolaminata	Kits van Waveren	P. caudata ss auct	
Psathyrella hydrophila var.	(Bull.ex Merat) Maire	variation ?	Waessringer Saumpilz
Psathyrella sp.		species unknown	
Psathyrella spadicea	(Sch->Kummer)Singer		
Ramaria pallida	(Sch)Ricken	R. mairei	
Russula albonigra var.	(Krombh.)Fr. / Romagn	var. Pseudonigricans	Schwarzweisser Taeubling
Russula brunnoviolacea	Crawshay		Braunvioletter Taeubling
Russula fella	(Fr.)Fr. / (FR:Fr) Fr		Gallentaeubling
Russula kromboholzii	R Shaffer	R.atropurpurea	
Russula luteotacta	Rea		Gelbfleckender Taeubling
Russula orcheoleuca	(Hall)Pers / (Pers.ex Secr.)Fr		Zitronentäubling,Yellow Russula
Russula queletii	Fr		
Scleroderma aerolatum	Ehrenb.		Netzbovist
Scleroderma citrinum	Pers. / Pers:Pers	S.vulgare=S.aurantium	Kartoffelbovist, Earth Ball
Stereum rugosum	(Pers. ex Fr.)Fr.		Runzeliger Schichpilz
Trichologlossum hirsutum	(Pers:Fr.)Boud		Earth Tongue
Tricholoma fulvum	(DC. ex Fr.)Sacc. / (Bull:Fr)Saccardo	T. flavobrunneum	Gelbblaetriger Ritterling
Tricholoma sulphureum	(Bull ex Fr.) Kummer		Schwefelritterling
Tricholoma sulphureum var.			
Tricholoma terreum	(Schaeff. ex Fr.) Kummer		Graublaettriger Erdritterling
Tyromyces albellus	(Peck.)Boud & Sing.	Aurantioporus/Oligoporus	Leder-Saftporling
Xerocomus badius	(Fr:Fr)Gilbert		Bay Bolete
Xerocomus chrysenteron	(Bull)Quelet		Red-crackling Bolete
Xerocomus parasiticus	(Bull:Fr)Quelet	Pseudoboletus p.	
Xylaria hypoxylon	(L.ex Hook.)Greville	Candle Snuff	Geweihfoermige Holzkeule
Xylaria longipes	Nitschke / (Alb.&Schw:Fr)Fr	Dead Man's Fingers	Langstielige Holzkeule

Appendix 2C: Merzalben Mushroom Fruiting Body Collection - Habitat Notes

Key at end.

	Abundance 4>3>2>1>0				General Information:		
	Limed		Unlimed				
Genus species	2000	2001	2000	2001	Local	Forest Habitats	Habitat Notes
Agaricus langei			1		N.Af. E	C	
Agaricus silvaticus				2	N.Af. E	C	Scattered, similar to A. phaeolepidotus
Agrocybe pusiola				1	E	Moss & grass	Rare, open areas
Amanita citrina	1		3	1	N.Af. E	Beech, D&C	Fall
Amanita citrina var.					N.Af. E	Beech, D&C	Fall, common
Amanita eliae				2	E	Oak, D	Scattered to very rare
Amanita eliae var.				2			
Amanita pantherina				1	N.Af. E	D&C	Rare,absent above 60 degrees North
Amanita rubescens	1		1	2	N.Af. E	D&C	Summer & fall, common
Armillaria bulbosa var.				1	N.Af. E	Wood	Parasitic,Saphrophitic,rhizomorphs,common
Armillaria mellea				2	N.Af. E	D&C-dead wood	Fall,Parasitic under bark,common
Armillaria ostoyae		3		3	N.Af. E	D&C	Parasitic then saphrophytic
Armillaria ostoyae var.				1			
A. ostoyae var. Mal.				1			
Bisporella citrina	2		1	1		D	Fall, dead wood
Boletus edulis		4		2	N.Af. E	Spruce,Oak,Beech	Fall,acid soils,warm dry summers,common
Boletus erythropus	1			2	N.Af. E	Beech, D&C	Summer & fall, common, blues when cut
Boletus impolitus		3		2	N.Af. E	D-limed lowlands	Summer & fall, rare on limed moist lowland
Boletus porosporus	2					Oak, D,M	Fall
Callistorporium olivascens				1	F.I.S.SI	Pine or cyprus	Rare.
Calocybe gambosa			1		N.Af. E	Meadows, woods	Spring, common often in rings
Calvatia cinerea	1						
Calvatia excipuliformis	1				N.Af. E	Forest & Field	Summer & fall,common
Cariola versicolor		2			N.Af. E	On wood	Very common
Cineromyces linbladii		1					
Clinocybe infundibuliformis			1		N.Af. E	C-moss,grass	Summer & fall, very common
Clitocybe graminocola		1			E	Grassy places	rare
Collybia butyracea		1	1		N.Af. E	D&C	Summer & fall, acid soils
Collybia erythropus		1			N.Af. E	D ,'M-buried wood	Summer & fall in rotting matter, frequent
Collybia kuehneriana		1					
Conocybe subovalis				1	N.Af. E	D, grassy places	Frequent to rare
Coriolus versicolor			1		N. Af. E	D & seldom C	Winter,dead branches, stumps, common
Cortinarius pallustris				2	E, G	In moss	Scattered
Cortinarius pholideus				2	E	Birch & C	Fall, moist woods, damp acid soils
Cortinarius sp.	1						
Daedalea quercina		1			N. Af. E	Oak,D	Stumps, posts, common
Diatrype disciformis	2					D & Red beech	all year on dead branches
Entoloma porphyrophaeum			1		E	Grass & fields	Spring to fall, poor soils, rare
Entoloma rhodopolium var.		3			N.Af.E	D	Summer to fall
Gleophyllum oebratum		1					
Grifola umbellata		2				D, old forest, oak	Summer to fall, old forest
Hebeloma austuliniforme			1				
Hebeloma strosphosa			1				
Hydropus atramentosus	2				E, G	C	Rotten trees, blackens when bruised
Hygrocybe psittacina		1		2	N.Af.E	Grass, fields, moss	Summer to fall,scattered

Appendix 2C: Merzalben Mushroom Fruiting Body Collection - Habitat Notes

Key at end

	Abundance 4>3>2>1>0				General Information:		
	Limed		Unlimed				
Genus species	2000	2001	2000	2001	**Local**	**Forest Habitats**	**Habitat Notes**
Hypholoma capnoides		**1**		**2**	E	C	Branches, stumps, roots, scattered
Hypholoma fasiculare	**4**	**4**	**3**	**3**	N.Af.E	M	Stumps, tree wood, all year
Hypholoma sublateritium			**1**		N.Af.E	D, seldom C	Spring to Fall, stumps,scattered
Hypochnicium vellereum		**1**				D	Fall
Inocybe fastigiata	**1**				E, G	D,Open woods	Summer to Fall, along roads,common
Inocybe praetervisa			**1**		N.Af.E	Beech, D, C	Summer, prefers calcarious soils
Inocybe sp.	**1**		**1**				
Lactarius quietus				**2**	N.Af.E	Oak, D	Fall, common
Laccaria amethystina	**3**	**2**	**2**	**3**	N.Af.E	Birch,D	Summer to fall cold forest edges
Laccaria bicolor		**2**		**1**	N.Af.E	Pine	Summer to fall, wood edge
Laccaria laccata	**3**				N.Af.E	M, open	Exposed areas
Laccaria tortilis				**1**	E	Ferns	Fall, moist woods, ruts, muddy places,rare
Lachnellula subtilissima		**2**				C	Fall,rare
Lactarius blennius			**1**		N.Af.E	Beech, D	Summer, fall, common, scattered
Lactarius chrysorrheus			**1**		N.Af.E	Oak, D	Summer, fall, common, scattered
Lactarius deterrimus			**2**		E	Spruce	Common
Lactarius helvis	**1**				E	C, birch	Moors & Hedges, damp woods
Lactarius pallidus var.		**1**			E	Beech,Birch	Cold beech
Lactarius quietus	**2**		**1**	**2**	N.Af.E	Oak, D	Fall,very common
Lactarius rufus			**3**		E	D,Birch & C,Pine	Common, acid soil, acid odor
Lactarius sp.	**3**	**1**	**1**				
Lactarius subdulcis	**1**		**1**		N.Af.E	Beech,D	Summer to fall, common, rubber smell
Lactarius volemus	**1**				N.Af.E	D&C	Fall,common to scattered, artichoke smell
Lepiota mastoidea	**1**				N.Af.E	Open woods	Summer to fall,Frequent
Lepiota rhacodes var.				**1**	N.Af.E	C, edges	Common, disturbed sites, N rich soil
Lepiota sp.	**1**						
Lepista nuda			**2**		N.Af.E	Woods	Fall, Humus soil, fairy rings,perfume smell
Lepista sordida var.	**2**				N.Af.E	Grass. fields, parks	Fall, fairy rings, very common
Leucocortinarius bulbiger				**1**	E, G	C	Fall,Frequent to rare
Lycoperdon perlatum	**2**	**1**			N.Af.E	M	Summer to Fall, very common
Macrolepiota mastoidea		**3**		**3**	N.Af.E	Open woods	Summer to fall,Frequent
Macrolepiota procera		**2**		**1**	N.Af.E	D,edges, grass	Open areas, common
Marasmius androsaceus			**2**	**1**	N.Af.E	C	Common
Marasmus coharens				**1**	E	M	Scattered to rare
Melanoleuca ingrata var.				**1**			
Merulius tremalosus blass		**1**			N.Af.E	D-stumps	Aug.-Apr.,fallen trees, Frequent to rare
Mycena aetites			**1**		E	Grass, Hay	Fall,Scattered to rare
Mycena filopes		**1**			E	D,M-rotten wood	Fall, Moist, litter, bark, common
Mycena galericulata	**1**		**1**	**1**	N.Af.E	M-rotten wood	Summer to fall,common
Mycena inclinata				**1**	N.Af.E	Oak, D-stumps	Summer to fall, branches, frequent
Mycena lactea		**1**				C,Spruce, Fir	Summer to fall, in Needles
Mycena leucogala var.	**1**	**2**		**2**		D.M	Fall
Mycena pura		**3**		**2**	N.Af.E	Red beech,woods	Summer to fall,radish smell,groups,common
Mycena rosella	**2**				E	C	Needles, Frequen to scattered
Mycena sepia	**2**					C	Fall

Appendix 2C: Merzalben Mushroom Fruiting Body Collection - Habitat Notes

Key at end

	Abundance 4>3>2>1>0				General Information:		
	Limed		Unlimed				
Genus species	2000	2001	2000	2001	Local	Forest Habitats	Habitat Notes
Mycena sp. (nivepes)		1				Pine,Mixed	stumps
Mycena speirea		1			N.Af.E.G	D litter	Fall, wood, twigs, litter, common to rare
Mycena uracea		1					
Myxomphalina maura			1		N.Af.E	Bonfire sites	Burned areas, common to rare
Oudemansiella pudens	1				E	D-buried wood	Attached to roots, Scattered
Panaelus fimicola	1				N.Af.E	Roadsides	Meadows, tracks, short grass, common
Panaeolus alter		1			E	Grass under trees	Spring to Fall, tracks, parkland, scattered
Panaeolus campanulatus		1			N.Af.E	Manured meadows	In horsedung, mainly meadows,rare
Paneolus sp.		1					
Paxillus involutus			1	2	E	D& C	Grasslands, moist places, kidney problems
Paxillus involutus var.				2	E	C	Summer to fall,stumps,grass clumps,F-R
Pluteus diettrichii				1	E, G	D, Ash	Woody debris or in soil, rare
Psathyrella atrolaminata	1	1			E	M-wood edges	Buried woody debris, Freqent to rare
Psathyrella hydrophila var.				1		D	Fall, stumps, large grass clumps
Psathyrella sp.				2			
Psathyrella spadicea		2		2	N.Af.E	D	Base of trees, stumps
Ramaria pallida			1		N.Af.E	Woods	On ground, Scattered to rare
Russula albonigra var.				2	N.Af.E	D& C	Summer to Fall, frequent to rare
Russula brunnoviolacea				2	E	Oak, D	Summer to fall, acid soil, common-scarce
Russula fella			1		E	Beech, D	Summer to fall, Common, scattered
Russula kromboholzii		1			E	Woods	Common to scattered
Russula luteotacta			1		E, G	D-damp places	Summer to fall, Frequent to rare
Russula orcheoleuca	1	4	3	4	E	C, Spruce, Aspen	Summer to fall,common
Russula queletii	1		1		E	C, Spruce	Neutral to lime soils, Common, scattered
Scleroderma aerolatum			2		E, G	Wood edges	Summer to fall,Moist poor soil
Scleroderma citrinum	1				N.Af.E	Wood,Path,Fields	Summer to fall, sandy acid soil,parasite
Stereum rugosum		1			E	Dead D. trees	Winter,Stumps, dead branches
Trichologlossum hirsutum		1			E	Moss, grass	Summer to fall, acid soil, common
Tricholoma fulvum				2	N.Af.E	Birch, D, M	Summer to fall, common
Tricholoma sulphureum	3				N.Af.E	D&C	Summer to fall, acid soil, social
T. sulphureum var.	1						
Tricholoma terreum				1	N.Af.E	D&C	Fall, scattered, esp. calcareous soil
Tyromyces albellus				1	E	D&C	Summer to fall, dead wood
Xerocomus badius	3		2		N.Af.E	Woods	Summer to fall, acid soil, common
Xerocomus chrysenteron			1		N.Af.E	Woods	Summer to fall, common
Xerocomus parasiticus					E, G		Parasitic on Scleroderma,scattered to rare
Xylaria hypoxylon	2	3				D	Winter,dead wood,common
Xylaria longipes	2					Maple	All year, stumps and branches

Key to Appendix 2C:
Local: E = Europe, F = France, G = Germany, I = Italy, N.Af = North Africa, S = Spain, Sl = Slovinia
Forest Habitats: C = Coniferous, D = Deciduous, M = Mixed

Appendix 2D: Merzalben Mushroom Fruiting Body Collection -Dendrology

Key at end of Appendix 2D

Genus species	S	C	Subclass	Order/Suborder	Family/Subfamily
Agaricus langei	B	H	Agaricomycetideae	Agaricales	Agaricaceae
Agaricus silvaticus	B	H	Agaricomycetideae	Agaricales	Agaricaceae
Agrocybe pusiola	B	H	Agaricomycetideae	Cortinariales	Bolbitiaceae
Amanita citrina	B	H	Agaricomycetideae	Amanitales	Amanitaceae
Amanita citrina var.	B	H	Agaricomycetideae	Amanitales	Amanitaceae
Amanita eliae	B	H	Agaricomycetideae	Amanitales	Amanitaceae
Amanita eliae var.	B	H	Agaricomycetideae	Amanitales	Amanitaceae
Amanita pantherina	B	H	Agaricomycetideae	Amanitales	Amanitaceae
Amanita rubescens	B	H	Agaricomycetideae	Amanitales	Amanitaceae
Armillaria bulbosa var.	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae/Tricholomatoideae
Armillaria mellea	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae/Tricholomatoideae
Armillaria ostoyae	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae/Tricholomatoideae
Armillaria ostoyae var.	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae/Tricholomatoideae
Armillaria ostoyae var. Mal.	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae/Tricholomatoideae
Bisporella citrina	A	Hy			
Boletus edulis	B	H	Agaricomycetideae	Boletales	Boletaceae
Boletus erythropus	B	H	Agaricomycetideae	Boletales	Boletaceae
Boletus impolitus	B	H	Agaricomycetideae	Boletales	Boletaceae
Boletus porosporus	B	H	Agaricomycetideae	Boletales	Boletaceae
Callistorporium olivascens	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae
Calocybe gambosa	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae / Lyophylloideae
Calvatia cinerea	B	H			
Calvatia excipuliformis	B	H	Gastromycetideae	Lycoperdales	Lycoperdaceae
Cariola versicolor	B	H	Aphyllophoromycetideae	Polyporales	Coriolaceae
Cineromyces linbladii					
Clinocybe infundibuliformis	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae
Clitocybe graminocola	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae
Collybia butyracea	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae
Collybia erythropus	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae
Collybia kuehneriana	B	H			
Conocybe subovalis	B	H	Agaricomycetideae	Cortinariales	Bolbitiaceae
Coriolus versicolor	B	H	Aphyllophoromycetideae	Polyporales	Coriolaceae
Cortinarius pallustris	B	H	Agaricomycetideae	Cortinariales	Cortinariaceae
Cortinarius pholideus	B	H	Agaricomycetideae	Cortinariales	Cortinariaceae
Cortinarius sp.	B	H			
Daedalea quercina	B	H	Aphyllophoromycetideae	Polyporales	Fomitopsidaceae
Diatrype disciformis					
Entoloma porphyrophaeum	B	H	Agaricomycetideae	Entolomatales	Entolomataceae
Entoloma rhodopolium var.	B	H	Agaricomycetideae	Entolomatales	Entolomataceae
Gleophyllum oebratum	B	H			
Grifola umbellata	B	H			
Hebeloma austuliniforme	B	H			
Hebeloma strosphosa	B	H			
Hydropus atramentosus	B	H			
Hygrocybe psittacina	B	H	Agaricomycetideae	Tricholomatales	Hygrophoraceae

Appendix 2D: Merzalben Mushroom Fruiting Body Collection -Dendrology

Key at end of Appendix 2D

Genus species	S	C	Subclass	Order/Suborder	Family/Subfamily
Hypholoma capnoides	B	H	Agaricomycetideae	Cortinariales	Strophariaceae
Hypholoma fasiculare	B	H	Agaricomycetideae	Cortinariales	Strophariaceae
Hypholoma sublateritium	B	H	Agaricomycetideae	Cortinariales	Strophariaceae
Hypochnicium vellereum					
Inocybe fastigiata	B	H	Agaricomycetideae	Cortinariales	Cortinariaceae
Inocybe praetervisa	B	H	Agaricomycetideae	Cortinariales	Cortinariaceae
Inocybe sp.	B	H	Agaricomycetideae	Cortinariales	Cortinariaceae
Lactarius quietus	B	H	Agaricomycetideae	Russuales	Russulaceae
Laccaria amethystina	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae
Laccaria bicolor	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae
Laccaria laccata	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae
Laccaria tortilis	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae
Lachnellula subtilissima	B	H			
Lactarius blennius	B	H	Agaricomycetideae	Russuales	Russulaceae
Lactarius chrysorrheus	B	H	Agaricomycetideae	Russuales	Russulaceae
Lactarius deterrimus	B	H	Agaricomycetideae	Russulales	Russulaceae
Lactarius helvis	B	H	Agaricomycetideae	Russulales	Russulaceae
Lactarius pallidus var.	B	H	Agaricomycetideae	Russulales	Russulaceae
Lactarius quietus	B	H	Agaricomycetideae	Russulales	Russulaceae
Lactarius rufus	B	H	Agaricomycetideae	Russulales	Russulaceae
Lactarius sp.	B	H	Agaricomycetideae	Russulales	Russulaceae
Lactarius subdulcis	B	H	Agaricomycetideae	Russulales	Russulaceae
Lactarius volemus	B	H	Agaricomycetideae	Russulales	Russulaceae
Lepiota mastoidea	B	H	Agaricomycetideae	Agaricales	Agaricaceae / Leucoprineae
Lepiota rhacodes var.	B	H	Agaricomycetideae	Agaricales	Agaricaceae / Leucoprineae
Lepiota sp.	B	H	Agaricomycetideae		
Lepista nuda	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae / Lepisteae
Lepista sordida var.	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae / Lepisteae
Leucocortinarius bulbiger	B	H	Agaricomycetideae	Tricholomatales	Dermolomataceae
Lycoperdon perlatum	B	H	Gasteromycetideae	Lycoperdales	Gastromycetideae
Lepiota mastoidea	B	H	Agaricomycetideae	Agaricales	Agaricaceae / Leucoprineae
Macrolepiota procera	B	H	Agaricomycetideae	Agaricales	Agaricaceae / Leucoprineae
Marasmius androsaceus	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Marasmus coharens	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Melanoleuca ingrata var.	B	H			
Merulius tremalosus blass	B	H	Aphyllophoromycetideae		
Mycena aetites	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Mycena filopes	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Mycena galericulata	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Mycena inclinata	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Mycena lactea	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Mycena leucogala var.	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Mycena pura	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Mycena rosella	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Mycena sepia	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae

Appendix 2D: Merzalben Mushroom Fruiting Body Collection -Dendrology

Key at end of Appendix 2D

Genus species	S	C	Subclass	Order/Suborder	Family/Subfamily
Mycena sp. (nivepes)	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Mycena speirea	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Mycena uracea	B	H	Agaricomycetideae	Tricholomatales	Marasmiaceae / Marasmieae
Myxomphalina maura	B	H	Agaricomycetideae	Tricholomatales	Lyophylloideae / Lyophylleae
Oudemansiella pudens	B	H	Agaricomycetideae	Tricholomatales	Dermolomataceae
Panaelus fimicola	B	H	Agaricomycetideae	Cortinariales	Bolbitiaceae
Panaeolus alter	B	H	Agaricomycetideae	Cortinariales	Bolbitiaceae
Panaeolus campanulatus	B	H	Agaricomycetideae	Cortinariales	Bolbitiaceae
Paneolus sp.	B	H	Agaricomycetideae	Cortinariales	Bolbitiaceae
Paxillus involutus	B	H	Agaricomycetideae	Tricholomatales	Hygrophoropsidaceae / Paxillaceae
Paxillus involutus var.	B	H	Agaricomycetideae	Tricholomatales	Hygrophoropsidaceae / Paxillaceae
Pluteus diettrichii	B	H	Agaricomycetideae	Pluteales	Pluteaceae
Psathyrella atrolaminata	B	H	Agaricomycetideae	Agaricales	Coprinaceae
Psathyrella hydrophila var. ?	B	H	Agaricomycetideae	Agaricales	Coprinaceae
Psathyrella sp.	B	H	Agaricomycetideae		
Psathyrella spadicea	B	H	Agaricomycetideae	Agaricales	Coprinaceae
Ramaria pallida	B	H	Aphyllophoromycetideae		
Russula albonigra var.	B	H	Agaricomycetideae	Russulales	Russulaceae
Russula brunnoviolacea	B	H	Agaricomycetideae	Russulales	Russulaceae
Russula fella	B	H	Agaricomycetideae	Russulales	Russulaceae
Russula kromboholzii	B	H	Agaricomycetideae	Russulales	Russulaceae
Russula luteotacta	B	H	Agaricomycetideae	Russulales	Russulaceae
Russula orcheoleuca	B	H	Agaricomycetideae	Russulales	Russulaceae
Russula queleti	B	H	Agaricomycetideae	Russulales	Russulaceae
Scleroderma aerolatum	B	H	Gasteromycetideae	Sclerodermatales	
Scleroderma citrinum	B	H	Gasteromycetideae	Sclerodermatales	
Stereum rugosum	B	H	Aphyllophoromycetideae		
Trichologlossum hirsutum	A	Hy	Pezizomycetideae,Discos	Leotiales,Helotiales	Geoglossaceae
Tricholoma fulvum	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae / Tricholomateae
Tricholoma sulphureum	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae / Tricholomateae
Tricholoma sulphureum var.	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae / Tricholomateae
Tricholoma terreum	B	H	Agaricomycetideae	Tricholomatales	Tricholomataceae / Tricholomateae
Tyromyces albellus	B	H	Aphyllophoromycetideae		
Xerocomus badius	B	H	Agaricomycetideae	Boletales	Boletaceae
Xerocomus chrysenteron	B	H	Agaricomycetideae	Boletales	Boletaceae
Xerocomus parasiticus	B	H	Agaricomycetideae	Boletales	Boletaceae
Xylaria hypoxylon	A	Hy	Pyrenomycetideae	Xylariales	
Xylaria longipes	A	Hy	Pyrenomycetideae	Xylariales	

Key for Appendix 2D
S = Subdivision. A = Ascomycotina, B = Basidiomycotina
C = Class, H = Homobasidiomycetes, Hy = Hymenoascomycetes

Appendix 2E: Merzalben Mushroom Fruiting Body Collection - Dendrology Continued & Source References

Key at end of Appendix 2E

Genus species	Tribe/Subtribe	Section/Subsection	M	Edible ?	Sources
Agaricus langei	Agariceae / Agaricus	Sanguinolentini/Sanguinolentini		Edible	C:160A736
Agaricus silvaticus	Agariceae / Agaricus	Sanguinolentini/Sanguinolentini		Edible ??	C:160
Agrocybe pusiola	Bolbiteae / Agrocybe				A:1307
Amanita citrina	Lepidella	Mappae	*M*	Poison	C:21A:855
Amanita citrina var.	Lepidella	Mappae	*M*	Poison	C:21A:855
Amanita eliae	Amanitia	Amanita	*M*	Poison	A:840
Amanita eliae var.	Amanitia	Amanita	*M*		
Amanita pantherina	Amanitia	Amanita	*M*	Poison	A:839
Amanita rubescens	Lepidella	Validae	*M*	P=raw	A:832
Armillaria bulbosa var.	Clintocybe / Armillaria			E-young	A:317
Armillaria mellea	Clintocybe / Armillaria			P=raw	C:33A:313
Armillaria ostoyae	Clintocybe / Armillaria			Poison	A:314
Armillaria ostoyae var.	Clintocybe / Armillaria				
Armillaria ostoyae var. Mal.	Clintocybe / Armillaria				
Bisporella citrina				Poison	C:276
Boletus edulis	Boletus	Edules	*M*	Poison	C:192A:1669
Boletus erythropus	Boletus	Luridi / Luridini	*M*	P-raw	C:201A:1681
Boletus impolitus	Boletus	Fragrantes	*M*	edible	C:196A:1678
Boletus porosporus	Boletus		*M*	edible	C:202
Callistorporium olivascens	Callistosporum			bitter	A:362
Calocybe gambosa	Lyophylleae	Calocybe=Lyophyllum		edible	A:482
Calvatia cinerea					
Calvatia excipuliformis	Calvatia			E-young	C:247A:1730
Cariola versicolor				no	A:95
Cineromyces linbladii					
Clinocybe infundibuliformis	Clintocybeae	Infundibuliformes		edible	C:48
Clitocybe graminocola	Clintocybeae	Odorae/Pseudocandicantes		Poison	A:298
Collybia butyracea	Collybieae	Collybia / Rhodocollybia		edible	C:57A:517
Collybia erythropus	Collybieae	Collybia		Poison	C:54A:525
Collybia kuehneriana					
Conocybe subovalis	Bolbitiaceae	Conocybe			A:1322
Coriolus versicolor				no	C:235A:95
Cortinarius pallustris	Dermocybe	Dermocybe			A:1122
Cortinarius pholideus	Cortinarieae	Cortinarius / Sericeocybe		no	C:132A:1112
Cortinarius sp.			*M*		
Daedalea quercina				no	C:233A:87
Diatrype disciformis				no	C:281
Entoloma porphyrophaeum	Entoloma	Turfosa / Tichopilus		edible**	C:1116A:933
Entoloma rhodopolium var.	Entoloma	Rhodophila		Poison	C:115
Gleophyllum oebratum					
Grifola umbellata				edible	C:220
Hebeloma austuliniforme					
Hebeloma strosphosa					
Hydropus atramentosus					A:634
Hygrocybe psittacina	Hygrocybeae	Psittacinae		edible	C:65A:228

Appendix 2E: Merzalben Mushroom Fruiting Body Collection - Dendrology Continued & Source References

Key at end of Appendix 2E

Genus species	Tribe/Subtribe	Section/Subsection	M	Edible ?	Sources
Hypholoma capnoides	Hypholoma=Naematoloma	Hypholoma		edible	C:159A:1289
Hypholoma fasiculare	Hypholoma=Naematoloma	Hypholoma		Poison	C:159A:1288
Hypholoma sublateritium	Hypholoma=Naematoloma	Hypholoma		Poison	C:159A:1287
Hypochnicium vellereum				no	C:241
Inocybe fastigiata	Inocybeae	Rimosae / Rimosinae		Poison	C:150A:1018
Inocybe praetervisa	Clypeus	Marginate / Rubellineae		no	C:153A:1083
Inocybe sp.					
Lactarius quietus	Russula	Russulares / Subdulcini		edible	C:88A:1581
Laccaria amethystina	Laccariae	Laccaria	*M*	edible	C:52A:352
Laccaria bicolor	Laccariae	Laccaria		barely edi	C:52A:353
Laccaria laccata	Laccariae	Laccaria		edible	A:355
Laccaria tortilis	Laccariae	Laccaria		edible	C:52A:359
Lachnellula subtilissima				no	C:279
Lactarius blennius	Lactarius	Glutinosi / Glutinosini		no	C:83A:1544
Lactarius chrysorrheus	Russula	Russulares / Subdulcini	*M*	Poison	C:79A:1579
Lactarius deterrimus	Russula	Dapetes / Deliciosini		edible	C:80A:1556
Lactarius helvis	Russula	Colorati / Coloratini		no	C:87A:1571
Lactarius pallidus var.	Russula	Glutinosi/Pyrogalini		no	C:83B:438
Lactarius quietus	Russula	Russulares / Subdulcini		edible	C:88A:1581
Lactarius rufus	Russula	Colorati / Rufini		no	C:87A:1569
Lactarius sp.	Russula				
Lactarius subdulcis	Russula	Russulares / Subdulcini	*M*	edible	C:89A:1582
Lactarius volemus	Russula	Volemi		edible	C:88A:1583
Lepiota mastoidea	Macrolepiota=Lepiota			edible	C:27A:712
Lepiota rhacodes var.	Macrolepiota=Lepiota			no	A:713
Lepiota sp.					
Lepista nuda	Rhodopaxillus			edible	C:113A:424
Lepista sordida var.	Rhodopaxillus			edible	C:113A:427
Leucocortinarius bulbiger	Leucocorinarius			no	C:123A:644
Lycoperdon perlatum				edible you	C:249A:1735
Lepiota mastoidea	Macrolepiota=Lepiota			edible	C:27A:712B:284
Macrolepiota procera	Macrolepiota=Lepiota			edible	A:714
Marasmius androsaceus	Marasmius	Anddrosacei			A:494
Marasmus coharens	Marasmius	Sicci			A:502
Melanoleuca ingrata var.					
Merulius tremalosus blass				no	C:239A:63
Mycena aetites	Mycena	Fragilipedes		Edible	C:72A:572
Mycena filopes	Mycena	Filipedes		No.	C:74A:553
Mycena galericulata	Mycena	Mycena		No	C:70'A:587
Mycena inclinata	Mycena	Mycena		No	C:72A:588
Mycena lactea	Mycena			No	C:76
Mycena leucogala var.	Mycena	Mycena / Fulginellae / Lactipedes		Edible	C:70A:596
Mycena pura	Mycena	Calodontes		Poison	C:72A:601
Mycena rosella	Mycena	Luculentae / Rosellae			A:560
Mycena sepia	Mycena			No	C:72

Appendix 2E: Merzalben Mushroom Fruiting Body Collection - Dendrology Continued & Source References

Key at end of Appendix 2E

Genus species	Tribe/Subtribe	Section/Subsection	M	Edible ?	Sources
Mycena sp. (nivepes)	Mycena				B:222
Mycena speirea	Mycena	Hiemales / Omphaliariae		No	C:75A:612
Mycena uracea					
Myxomphalina maura	Lyophyllum	Tephrocybe,Tephrophana,Lyco.		No	C:68A:486
Oudemansiella pudens	Oudemansiella			Edible	A:628
Panaelus fimicola	Panneolus				A:1339
Panaeolus alter	Panneolus			No	C:182A:1337
Panaeolus campanulatus	Panneolus			Poison	C:181 A:1340
Paneolus sp.	Panneolus				
Paxillus involutus	Paxillus		*M*	Poison	C:142A:1611
Paxillus involutus var.	Paxillus		*M*	No	C:143A:1612
Pluteus diettrichii	Pluteus	Celluloderma / Eu-Cellulodermini			A:892
Psathyrella atrolaminata	Psathyrella	Psathyrella			A:785
Psathyrella hydrophila var. ?	Psathyrella			edible	C:174
Psathyrella sp.					
Psathyrella spadicea	Psathyrella	Pseudostropharia			A:808
Ramaria pallida	Ramaria=Clavaria				A:128
Russula albonigra var.	Russula	Compactae		No	C:91A:1346
Russula brunnoviolacea	Russula	Heterophyllae / Sphagnophilineae		edible	C:103A:1443
Russula fella	Russula	Russula / Felleineae and Citrineae		No	C:94A:1364
Russula kromboholzii	Russula	Russula / Atropurpurineae			A:1381
Russula luteotacta	Russula	Russula / Emeticineae		Poison	C:103A:1368
Russula orcheoleuca	Russula	Lilaceae/Orcholeucineae	*M*	edible	C:94, I:85
Russula queleti	Russula	Firma / Sanguinineae			A:1397
Scleroderma aerolatum				No	C:250A:1727
Scleroderma citrinum				Poison	C:250A:1726
Stereum rugosum				No	C:236A:66x
Trichologlossum hirsutum				No	C:274A:8x
Tricholoma fulvum	Tricholoma	Albobrunea / Pessundatineae		Poison	C:39A:406
Tricholoma sulphureum	Tricholoma	Sericeocutis		Poison	C:35A:381
Tricholoma sulphureum var.	Tricholoma	Sericeocutis			
Tricholoma terreum	Tricholoma	Terrea / Tereineae		edible	C:35A:393
Tyromyces albellus				No	C:233A:99x
Xerocomus badius	Xerocomus		*M*	edible	A:1657
Xerocomus chrysenteron	Xerocomus		*M*		A:1653
Xerocomus parasiticus	Xerocomus		*M*		A:1659
Xylaria hypoxylon				No	C:278A:7
Xylaria longipes				No	C:278A:6

Key to Appendix 2E : Source citations are given on page 3 of Appendix 2.
M = Mycorrhizal, P = Poison, E = Edible
A = Courtlcuisse & Duhem (1993)
B = Hagara (1995)
C = Phillips (1998)

Appendix 3: General Damage Classes in Merzalben Forest

Purpose: The purpose of this appendix is to document the health status of the Merzalben oak forest as mentioned in Section A1-4.

Appendix 3A-1 & 3A-2: Communications from Hans Werner Schöck, 2003.

Appendix 3B: Crown Structure of the Unlimed and Limed Oaks in Merzalben

Appendix 3C: Growth Factors of Unlimed and Limed Oaks in Merzalben

Appendix 3D: Summary of the Factors that Influence Oak Crowns

Comments:

In light of the fact that the limed forest was found to contain more aluminum in the mycorrhizal roots than the unlimed forest, it was quite disconcerting to have such a discrepancy between the health status of the trees and that of their root systems. The trees in the limed forest were in much better shape than the trees in the adjacent, unlimed plot.

As will be shown eventually in this report, the majority of mycorrhizal species in the unlimed forest trees did not as effectively store or block Al, but rather allowed passage of aluminum directly into the root system which would in part account for the good health of the mycorrhizal roots but poor health of the trees. In the limed forest, the mycorrhizal species present were more effective at storing and blocking aluminum translocation, which would account for the poor appearance of the fungal symbionts and the roots but the better crown density and overall health of the trees.

Appendix 3A-1: Communication from Hans Werner Schöck, 2003.

Betreff: Eichen Merzalben
Datum: Mon, 31 Mar 2003 15:02:28 +0200
Von: "Hans-Werner Schr÷ck" <schroeck@rhrk.uni-kl.de>
An: rothe@mail.uni-mainz.de
CC: wilsonc@rheingau.vistec.net

sehr geehrte Frau Wilson,
sehr geehrter Herr Rothe,

anbei eine Datei mit der Kronenstrukturansprache (28.03.03) der von Frau Wilson untersuchten Eichen. Leider haben wir drei Bäume nicht mehr gefunden. Eine Eiche war vermutlich abgestorben und ist entnommen worden, die beiden anderen sind unklar.

Zu den Ergebnissen:
Eingewertet wurde die Kronenstruktur einerseits nach ROLOFF (inclusive einer sog. Feinstufe, wobei die ROLOFF-Stufe gedrittelt wurde) sowie nach dem Kronenstrukturschlüssel der AG-Dauerbeobachtungsflächen.
Die Ergebnisse zeigen eine etwas bessere Kronenstruktur der Eichen auf den gekalkten Flächen. Allerdings ist das Kollektiv recht klein, so daß die Ergebnisse entsprechend unsicher sind. Als Beispiel: in dem gekalkten Bereich sind seit 1998 drei Eichen abgestorben, eine der von Ihnen untersuchten Bäume ist absterbend.
Im ungekalkten Bereich sind im gleichen Zeitraum ca. 15 Bäume abgestorben.

Aus diesem Grund liegen in dem gleichen exel-file unter "Eichendauerbeobachtungsfläche" die Ergebnisse der erstmals 2002 im Sommer (Kronenverlichtung) und im Winter (Kronenstruktur) auf der gekalkten und ungekalkten Fläche gleichzeitig erfassten Bäume bei.

Die Ergebnisse sind eindeutig:auf der gekalkten Fläche sind sowohl Kronenverlichtung als auch Kronenstruktur deutlich! besser als auf der ungekalkten Fläche. D.h. die positive Wirkung der Kalkung auf den Kronenzustand bleibt für mich unzweifelhaft.

Eine weitere Frage an Frau Wilson: haben Sie den Durchmesser der Eichen (=als Vitalitätsindikator/ Hinweis auf Konkurrenzstärke) gemessen? Eventuell ist der Anteil unterschiedlicher Baumklassen nach KRAFT in den beiden Kollektiven unterschiedlich. Falls dies von Ihnen nicht geschehen ist könnten wir dies nachholen.

Falls weitere Fragen zu den Daten/sonst. offen sind melden sie sich bitte per mail.

Liebe Grüße
Hans Werner Schröck

Mit freundlichen Gruessen
Hans Werner Schroeck

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Schloß
67705 Trippstadt
Tel.: 06306-911-122 Fax : 06306-911-200
email: schroeck@rhrk.uni-kl.de

Appendix 3A-2: Communication from Hans Werner Schöck, 2003.

Betreff: Re: Eichen Merzalben
Datum: Wed, 02 Apr 2003 10:48:25 +0200
Von: "Hans-Werner Schr÷ck" <schroeck@rhrk.uni-kl.de>
An: "Gunter M. Rothe" <rothe@mail.uni-mainz.de>

Sehr geehrter Herr Rothe,

"Eistru" bedeutet eine Aufnahme der Kronenstruktur nach dem Schlüssel der AG-Dauerbeobachtungsflächen. (Wird von den Bundesländern mittlerweile einheitlich erfasst).

Das Problem war, dass der Schlüssel von ROLOFF nicht immer zu eindeutigen Zuordnungen geführt hat, weshalb ein neuer Schlüssel konzipiert wurde.
Im vorliegenden Fall können Sie auch lediglich den ROLOFF-Schlüssel verwenden, da nach unseren Erfahrungen ein relativ enger Bezug zwischen den beiden Schlüsseln besteht. Wir verwenden nach wie vor zur besseren Vergleichbarkeit der Zeitreihen beide Aufnahmeschlüssel.

Zu der Frage nach den zugrundeliegenden Baumzahlen hinsichtlich der Absterbevorgänge:
Die Flächengröße der Bezugseinheiten gekalkt zu ungekalkt sind in etwa identisch. Genaue Baumzahlen sind mir momentan nicht verfügbar, werden jedoch in Kürze noch erfasst.
In diesem Zuge werden wir auch die Durchmesser der von Frau Wilson untersuchten Bäumen messen.

mfg
HWS

Mit freundlichen Gruessen
Hans Werner Schroeck

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Appendix 3B: Crown Structure of the Limed and Unlimed Oaks in Merzalben

Key Translation:

Jahr = Year
405 = ungekalkt (Unlimed)
410 = gekalkt (Limed)
BNR = Baumnummer (Tree number)
BKL = Baumklasse (Tree damage class) -1= Dead, 0 (healthy) to 4 (seriously damaged)
UA = Information über Ausfall (Felled tree information) 0 =Alive, # = Age at death
ZAUS = Zeitpunkt des Aussscheidens (Removal date) Year (ie 99 or 2001) Month (2)
VLP = Kronenverlichtung in %, Sommer (Crown lght penetration in %, Summer)
Mittelwert = Average

MERZALBEN OAK FOREST - LIMED REGION

Jahr	[illegible]	BNR	BKL	UA	ZAUS	VLP
2002	410	31	2	0	0	10
2002	410	32	2	74	20022	-1
2002	410	33	2	0	0	15
2002	410	34	2	0	0	25
2002	410	35	2	0	0	15
2002	410	36	2	0	0	25
2002	410	37	2	0	0	25
2002	410	38	2	0	0	25
2002	410	39	2	0	0	20
2002	410	40	2	0	0	20
2002	410	41	2	0	0	35
2002	410	42	2	0	0	25
2002	410	43	2	0	0	20
2002	410	44	2	0	0	35
2002	410	45	2	0	0	20
2002	410	46	2	0	0	15
2002	410	47	2	0	0	35
2002	410	48	2	0	0	20
2002	410	49	2	0	0	20
2002	410	50	2	0	0	20
2002	410	51	2	0	0	25
2002	410	52	2	0	0	25
2002	410	53	2	0	0	20
2002	410	54	2	0	0	20
2002	410	55	2	0	0	25
2002	410	56	2	0	0	20
2002	410	57	2	0	0	20
2002	410	58	2	0	0	15
2002	410	59	2	0	0	20
2002	410	60	2	0	0	35
2002	410	61	2	0	0	20
2002	410	62	2	0	0	25
2002	410	63	2	0	0	20

Mittelwert	22,34375
Anteil ROLOFF=0	

Appendix 3B: Crown Structure of the Limed and Unlimed Oaks in Merzalben

Key Translation:

Jahr = Year
405 = ungekalkt (Unlimed)
410 = gekalkt (Limed)
BNR = Baumnummer (Tree number)
BKL = Baumklasse (Tree damage class) -1= Dead, 0 (healthy) to 4 (seriously damaged)
UA = Information über Ausfall (Felled tree information) 0 =Alive, # = Age at death
ZAUS = Zeitpunkt des Aussscheidens (Removal date) Year (ie 99 or 2001) Month (2)
VLP = Kronenverlichtung in %, Sommer (Crown lght penetration in %, Summer)
Mittelwert = Average

MERZALBEN OAK FOREST - UNLIMED REGION

Jahr	[illegible]	BNR	BKL	UA	ZAUS	VLP
2002	405	1	2	0	0	50
2002	405	2	2	0	0	30
2002	405	3	2	0	0	35
2002	405	4	2	0	0	30
2002	405	5	1	0	0	40
2002	405	6	-1	9	952	-1
2002	405	7	2	0	0	40
2002	405	8	2	0	0	30
2002	405	9	-1	12	992	-1
2002	405	10	-1	1	992	-1
2002	405	11	2	0	0	40
2002	405	12	-1	12	992	-1
2002	405	13	2	0	0	25
2002	405	14	2	0	0	35
2002	405	15	2	0	0	30
2002	405	16	2	0	0	35
2002	405	17	2	0	0	40
2002	405	18	2	0	0	25
2002	405	19	2	0	0	30
2002	405	20	2	0	0	30
2002	405	21	2	0	0	40
2002	405	22	2	0	0	40
2002	405	23	2	0	0	45
2002	405	24	2	0	0	30
2002	405	25	2	0	0	25
2002	405	26	2	0	0	30
2002	405	27	2	0	0	25
2002	405	28	2	0	0	40
2002	405	29	-1	12	20012	-1
2002	405	30	2	0	0	50
2002	405	31	2	0	0	15
2002	405	32	2	0	0	35
2002	405	33	1	9	952	-1
2002	405	34	2	0	0	35
2002	405	35	-1	73	902	-1
2002	405	36	2	0	0	50
2002	405	37	3	0	0	40
2002	405	38	-1	12	20002	-1
2002	405	39	2	0	0	40
2002	405	40	2	0	0	30
2002	405	41	2	0	0	15
2002	405	42	2	0	0	60
2002	405	43	2	0	0	25
2002	405	44	2	0	0	60
2002	405	45	2	0	0	15
2002	405	46	2	0	0	35
2002	405	47	2	0	0	45
2002	405	48	2	0	0	25
2002	405	49	-1	9	982	-1
2002	405	50	2	0	0	25
2002	405	51	2	0	0	45
Mittelwert						34,88095238
	Anteil ROLOFF=0					

Appendix 3C: Growth Factors of the Limed and Unlimed Oaks in Merzalben

Key Translation:

405 = ungekalkt (Unlimed)
410 = gekalkt (Limed)
BNR = Baumnummer (Tree number)
FRASS = Blattverlust durch Insektenfraß im Juni (Leaf damage due to insects in June)
-1= Tree dead, Range = 0 (No damage) to 5 (Strong damage)
FRUKT = Fruktifikationsstäke (Fruiting strength) 0= none, 1= some, 2= average, 3=strong
ROLOFF -Feinstufe = New measurement device under review where 0 (healthy) to 8 (severely damaged)
ROLOFF = New measurement device under review where 0 (healthy) to 3 (severely damaged)
Eistru = Egg (seedling?) distribution 0 (good) to 7 (poor)

MERZALBEN OAK FOREST - LIMED REGION

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2002	410	-1	0	3	1	3
2002	410	-1	-1	2	0	3
2002	410	-1	0	2	0	3
2002	410	-1	0	3	1	4
2002	410	-1	0	5	1	3
2002	410	-1	0	4	1	4
2002	410	-1	0	3	1	4
2002	410	-1	0	6	2	5
2002	410	-1	0	1	0	2
2002	410	-1	0	3	1	3
2002	410	-1	0	2	0	2
2002	410	-1	0	2	0	3
2002	410	-1	1	2	0	3
2002	410	-1	0	3	1	3
2002	410	-1	0	1	0	2
2002	410	-1	0	6	2	5
2002	410	-1	0	2	0	3
2002	410	-1	0	2	0	3
2002	410	-1	0	2	0	4
2002	410	-1	0	2	0	3
2002	410	-1	1	7	2	5
2002	410	-1	1	5	1	5
2002	410	-1	0	6	2	5
2002	410	-1	1	4	1	3
2002	410	-1	0	4	1	3
2002	410	-1	0	2	0	3
2002	410	-1	0	3	1	4
2002	410	-1	0	1	0	2
2002	410	-1	0	5	1	5
2002	410	-1	0	6	2	4
2002	410	-1	0	3	1	4
2002	410	-1	0	1	0	2
2002	410	-1	0	2	0	3

3,424242424
45

Appendix 3C: Growth Factors of the Limed and Unlimed Oaks in Merzalben

Key Translation:

405 = ungekalkt (Unlimed)
410 = gekalkt (Limed)
BNR = Baumnummer (Tree number)
FRASS = Blattverlust durch Insektenfraß im Juni (Leaf damage due to insects in June)
-1= Tree dead, Range = 0 (No damage) to 5 (Strong damage)
FRUKT = Fruktifikationsstäke (Fruiting strength) 0= none, 1= some, 2= average, 3=strong
ROLOFF -Feinstufe = New measurement device under review where 0 (healthy) to 8 (severely damaged)
ROLOFF = New measurement device under review where 0 (healthy) to 3 (severely damaged)
Eistru = Egg (seedling?) distribution 0 (good) to 7 (poor)

-

MERZALBEN OAK FOREST - UNLIMED REGION

[illegible]	[illegible]	FRASS	FRUKT	ROLOFF-Feinstufe	ROLOFF	Eistru
2002	405	0	0	7	2	7
2002	405	5	0			
2002	405	0	0	4	1	4
2002	405	5	0	4	1	4
2002	405	0	0	5	1	5
2002	405	-1	-1			
2002	405	0	0	6	2	5
2002	405	0	2	5	1	4
2002	405	-1	-1			
2002	405	-1	-1			
2002	405	0	0	7	2	5
2002	405	-1	-1			
2002	405	0	2	6	2	4
2002	405	0	2	6	2	4
2002	405	5	0			
2002	405	0	1	5	1	4
2002	405	0	2	5	1	5
2002	405	0	0	6	2	5
2002	405	5	0	4	1	4
2002	405	0	0	4	1	4
2002	405	5	0	5	1	4
2002	405	0	0	5	1	4
2002	405	0	2	6	2	5
2002	405	0	0	5	1	4
2002	405	0	1	5	1	4
2002	405	0	0	4	1	4
2002	405	0	0	5	1	4
2002	405	5	0	5	1	4
2002	405	-1	-1			
2002	405	5	0	5	1	6
2002	405	0	0			
2002	405	0	0	6	2	5
2002	405	-1	-1			
2002	405	0	0	5	1	4
2002	405	-1	-1			
2002	405	0	0	7	2	6
2002	405	0	0			
2002	405	-1	-1			
2002	405	0	0	4	1	4
2002	405	0	1	6	2	5
2002	405	0	2	3	1	3
2002	405	0	0	7	2	5
2002	405	0	0	6	2	4
2002	405	0	0			
2002	405	0	0	4	1	4
2002	405	0	0	6	2	4
2002	405	0	0	7	2	5
2002	405	0	2	6	2	5
2002	405	-1	-1			
2002	405	0	2	6	2	5
2002	405	5	0	9	3	6
						4,540540541
					0	

Das Level II
Programm
in Rheinland-Pfalz

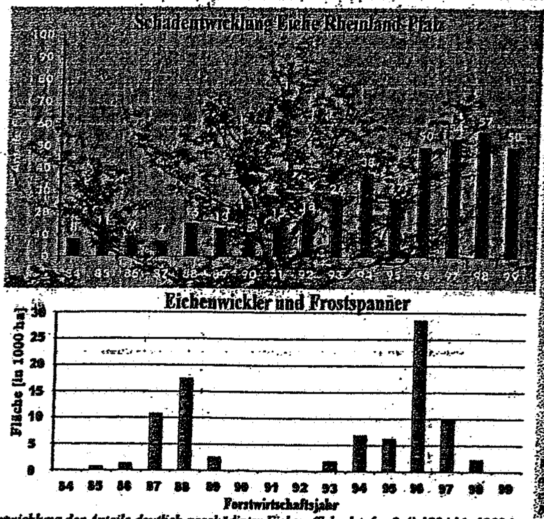
am Beispiel der

Erfassung von Einflussfaktoren auf den Kronenzustand von Eichen

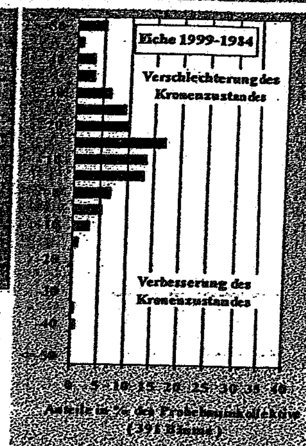
von H.W. Schröck, J. Block und F. Engels

Rheinland-Pfalz beteiligt sich mit 7 Flächen am europaweiten Level II-Programm. Da Eichenwälder mit 14% einen erheblichen Anteil an der Waldfläche des Landes einnehmen, wurden zwei Level II-Flächen in Eichenökosystemen eingerichtet.
Die rheinland-pfälzischen Level II-Standorte sind Teil eines 1982 begonnenen Programms zur Erforschung großräumiger Waldschäden (BLOCK 1995).
Hierin dienen landesweite Übersichtserhebungen wie die Waldschadens- und Bodenzustandserhebung der flächenrepräsentativen Erfassung des Waldzustandes und seiner Entwicklung und intensive Untersuchungen an 39 ausgewählten Waldstandorten der Ursache-Wirkungsanalyse.

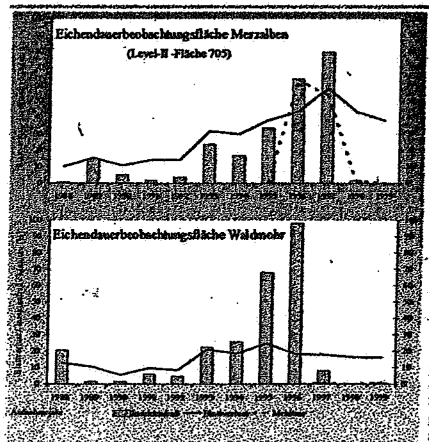
Schadentwicklung Eiche
Der Kronenzustand der Eiche hat sich in den 90er Jahren landesweit deutlich verschlechtert (MUF 1999). In vielen Eichenbeständen sind einzel- bis gruppenweise Absterbeerscheinungen zu beobachten.
Die Ursachendiskussion misst neben Einflüssen von Luftschadstoffen, Raupenfraßkalamitäten und in deren Folge erhöhten Befallsdichten von Eichenprachtkäfern besondere Bedeutung bei.
Während die Eichenwickler- und Frostspanner-Gradation 1987/88 ohne negative Auswirkungen auf den Kronenzustand des Eichenkollektivs der Waldschadenserhebung blieb, ging die Gradation Mitte der 90er Jahre mit einer Verschlechterung des Kronenzustandes einher.



Entwicklung der Anteile deutlich geschädigter Eichen (Schadstufen 2-4) 1984 bis 1999 in Rheinland-Pfalz (obere Grafik) und von den Forstämtern gemeldete Flächen mit merklichen Raupenfraßschäden an Eiche (untere Grafik).



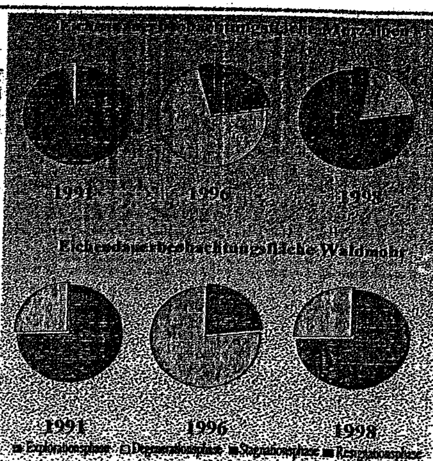
Veränderung der Kronenverlichtung 1984 auf 1999: dargestellt sind Anteile des Eichenkollektivs der Waldschadenserhebung, die gleiche (Differenz 0) bzw. angestiegene (+5...) oder gesunkene (-5...) Blattverluste aufweisen.



Entwicklung der Kronenverlichtung (mittlerer Blattverlust im August) in Abhängigkeit von Fraßschäden (mittlerer Blattverlust durch Raupen bei Abschluss des Fraßes im Juni) und Mehltau-befall (mittlerer Anteil sichtbar befallener Blätter im August)

Fraßschäden
Eine eingehende Analyse des Einflusses von Fraßschäden auf die Kronenzustandsentwicklung der Eichen ist nur anhand von Intensivuntersuchungen möglich. Daher werden an allen Eichendauerbeobachtungsflächen seit 1988 einzelbaumweise Fraßschäden im Juni erfasst (SCHRÖCK 1994).

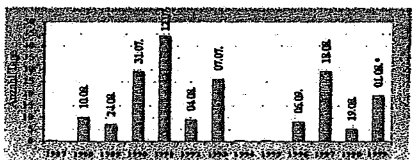
Regenerationsfähigkeit
Die Fähigkeit der Eichen zur Regeneration der Fraßschäden ist von Standort zu Standort sehr unterschiedlich. So veränderte sich die Kronenverlichtung auf der Fläche Waldmohr trotz starkem Raupenfraß 1995 und 1996 nur sehr wenig. Auf der Fläche Merzalben reagierten die Eichen demgegenüber auf den Raupenfraß mit einer deutlichen Zunahme der Kronenverlichtung und einer Verschlechterung der Kronenstruktur. An diesem Standort wurden 1996 und 1997 die Regenerationstriebe durch Mehltau befallen. Dies dürfte die negativen Auswirkungen des Raupenfraßes verstärkt haben. Allerdings wurde der Mehltaubefall durch die sehr zögerliche Regeneration der Blätter begünstigt, weshalb er eher als Folge denn als primäre Ursache der Vitalitätsverschlechterung anzusehen ist.



Entwicklung der Kronenstruktur (Bonitierung nach ROLOFF 1989) an zwei Eichendauerbeobachtungsflächen.

Als disponierender Faktor für die schlechte Regenerationsfähigkeit des Eichenbestandes Merzalben kommt der ungünstige chemische Bodenzustand und die schlechte Nährstoffverfügbarkeit dieses Standortes in Betracht (Basensättigung <10 %, Mg-Vorrat im Boden <50 kg/ha, Ca/Al 0,3).

Trockenstress
Als weiterer Einflussfaktor wird am Standort Merzalben die Trockenstressbelastung geprüft. Diesbezügliche Kennwerte werden aus Tensiometer- und TDR-Messungen abgeleitet sowie mit Hilfe eines Wasserhaushaltsmodells berechnet. Bisher ergaben sich keine Belege für Trockenstressbelastungen als Ursache für die deutliche Verschlechterung des Kronenzustandes der Eichen.



Trockenstress an der Eichenfläche Merzalben (705) (Säulen: Anzahl der Tage mit einer Saugspannung von >900hPa in 10 cm Bodentiefe; Datum über den Säulen: Beginn einer mehrtägigen Trockenperiode im jeweiligen Jahr) * bis 01.09.1999

Als biologischer Indikator für Trockenstress wird seit Sommer 1998 das tägliche Quellen und Schwinden der Bäume mit Hilfe hochauflösender Umfangmessungen erfasst. Es wird sich zeigen, ob auch diese Untersuchungen eine hohe Trockenstresstoleranz der Eiche belegen.

Schwammspinnerschäden
Während an der Fläche Merzalben die Ursachen der Vitalitätsverschlechterung sehr komplex zu sein scheinen, sind die extremen Schäden an der Eichendauerbeobachtungsfläche Hagenbach (Level II Fläche 706) im wesentlichen auf Schwammspinnerfraß zurückzuführen. Nach Lichtfraß in 1993 und Kahlfraß in 1994 sind in diesem Bestand 60 % der Eichen abgestorben. Das Absterben erfolgte weitgehend unabhängig von der Vitalität vor dem Kahlfraßereignis. Neben der Fraßintensität hatte der Standort den größten Einfluss auf die Mortalitätsrate (SCHRÖCK 1999). Sie stieg mit zunehmender Bodennässe deutlich an.

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SCHRÖCK, H.W. (1999): Einfluß eines Licht- und Kahlfraßes durch Schwammspinnerraupen auf die Vitalität eines Stieleichenbestandes auf einem hydromorphen Standort im Bienwald. Mitteilungen aus der Forstlichen Versuchsanstalt Rheinland-Pfalz Nr. 45, 134-150

Nach Schwammspinnerfraß abgestorbene Stieleichen im Bienwald.

Appendix 4: General Stress Factors

Appendix 4-1: Introduction

Appendix 4-2: Major Declines

Appendix 4-3: Abiotic Factors

4-3-1: Drought induced by Pollution and Precipitation Patterns

4-3-2. Thermal - Water Relations : Summer and Winter Embolisms

4-3-3: Drought Induced Sugar Changes

4-3-4: Drought Altered Nitrogen Metabolism

Appendix 4-4: Biotic Factors

4-4-1: Insects

4-4-2: Fungi

4-4-3: *Phytophthora cinnamomi*

4-4-4: *Phytophthora ramorum*

4-4-5: Armillaria spp: An Opportunistic Threat

4-4-6: Viral Factors

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Appendix 4: General Stress Factors
Appendix 4-1: Introduction.

Due to the high economic value of oaks, whenever they are subject to severe stresses, foresters worry. It is generally accepted now that declines or disorders are usually not attributable to any single cause but rather a combination of factors. Primary stressors tend to be associated with general abiotic climatic events such as winter frosts, air pollution, and severe drought which is the leading contributor to affliction. Secondary stressors usually involve opportunistic biotic interference with normal growth caused by variable, synergistic or cumulative factors including insect, fungal, or viral invasions of susceptible tissues. Because of the longevity of oaks, their decline is generally a long lasting and gradual process. Even in acute cases, demise of an affected mature tree often occurs several seasons or years after the initial stress.

It is important not to ignore the presence and health of the symbiotic mycorrhizae that colonize the rhizosphere and play a significant role in nutrient and water uptake. The loss of mycorrhizae can seriously hamper seedling maturation and adult survival. The presence of introduced oak subspecies species outside their natural range can contribute to location-specific catastrophic losses if the transferred mycorrhizal complements are not well adapted and suffer setbacks. This added to other stresses can be fatal.

Maladies related to the consequences of stress depend upon the intensity, duration and frequency of the stress. Stress models often describe disease spirals where as time progresses, the symptoms of decline become additive until the tree is incapable of recovery. Abiotic stress alone can lead to demise, but more frequently as susceptibility increases, biotic influences finish the process. "Opportunistic organisms are ubiquitous inhabitants of natural ecosystems functioning as ecosystem rogues, killing weak, defective trees and as scavengers decomposing the dead trees." (Wargo, 1996). When unusual abiotic factors stress normally vigorous trees, these facultative parasites can sometimes get out of control.

Appendix 4-2: Major Declines

Major periods of decline of *Q. petraea* and *Q. rubor* in northern and central Europe (including Germany and France) in the 1920's, 1940-50's and 1980's, have stimulated widespread investigations into their cause (Hartman et al, 1991; Brasier, 1996). In the 1940-1960's oak decline was widely attributed to vascular mycosis involving one or more of the fungi in the genera *Ophiostoma* or *Ceratocystis*, but this explanation has recently been discounted (Siwecki and Liese, 1991). The following is a summary of other possible causes of oak decline. Because they can be contributing factors, and not related directly to mycorrhizal - aluminum and acid stresses, they are included here only in the appendix.

Appendix 4-3: Abiotic Factors

Extreme single events can trigger oak decline without contribution of other factors, as in the major droughts which occurred from 1911-1920 in northern Germany (Hartman and Blank, 1992) and in France in 1975 (Becher and Lévy, 1982). Multiple events of a less-extreme nature can, over time, produce the same result. Severe and prolonged drought stress in the mid-1950's acted to predispose Appalachian populations of physiologically mature oaks to decline when subsequently stressed by a series of short-term but acute droughts in the mid-1980's in the USA (Tainter et al, 1990, Oak et al, 1996). In the Mediterranean region, oak decline, which began in 1983-4 and progressed to extremely serious decline by 1989, was statistically correlated to a seasonal drop in rainfall, particularly August precipitation (Vannini et al, 1996).

The present decline in northern Germany began in 1982, however, the growth reductions coincided with drought (1982), a heat wave (1983) (Heukamp, 1989) and severe winter weather (1984 &1985) (Dujesiefken & Balder, 1990), and insect defoliation (Hartman and Blank, 1992). It was estimated in 1988 that nearly 70% of the oaks in Germany were suffering decline symptoms (Balder, 1989). Cumulative environmental influences are now considered to be the primary stressors. Episodes of severe drought, waterlogging, air pollution or cold may cumulatively initiate decline symptoms and lead to chronic problems and secondary attack by opportunistic insects and pathogenic fungi. (Wargo, 1996). Many forests in Germany are "island" populations. Forest fragmentation increases the risk of sun scald, wind, drying and temperature extremes at the newly created forest edges.. Soil and litter organisms are especially vulnerable to warming and drying (Amaranthus and Perry, 1994, Perry et al, 1990). Drought has been implicated as a major stress factor in oaks in eastern and midwestern United States (Tainter et al, 1983) and Europe (Delatour 1983) (Wargo, 1996).

4-3-1: Drought induced by Pollution and Precipitation Patterns

According to Kaufman et al (2002), each cloud drop requires an aerosol particle to condense upon, thus these cloud condensing nucleii determine the cloud properties, evolution and precipitation patterns. For example: In clean air, cloud droplet size increases as the cloud develops until the droplet size exceeds ~ 15μm for the onset of precipitation or alternatively once the cloud top temperature reaches -10 ^{0}C the drop may freeze and drop as snow or sleet. However in polluted air, satellite data show not only smaller drop sizes (5-8) μm but no increase in drop size as the cloud develops, rising through the atmosphere and accumulating water vapor. As a result precipitation does not occur or is delayed. As a secondary effect, cloud water content, coverage area and lifespan increases, and in addition, the freezing process is delayed until the polluted cloud is supercooled to -37.5 ^{0}C. Updrafts and wind patterns play a role in altering the geographic location, duration, severity and type of precipitation. Because the continents are more polluted than the oceans, this can cause a loss of fresh water over the continents, particularly in highly polluted populated areas to the more distant pristine regions and the oceans (Kaufman et al, 2002). There is no evidence of atmospheric pollution in the Sierra de Gata region of Spain (Moreno et al, 1996) but considerable pollution in central and northern Europe (Mayer and Ulrich, 1980, Miller et al, 1987). In conjunction with the excessive precipitation experienced in the regions of eastern Europe in 2002, we may be seeing the beginning of major eastward shifts in rainfall over the European continent. This would have long term negative impact on the Merzalben forest.

4-3-2. Thermal - Water Relations : Summer and Winter Embolisms

The probability of vascular dysfunction increases with vessel size, drought, and freezing-induced embolism, the last of which, in extremely cold climates, may limit the range of

Quercus petraea Matt Liebl (Tyree & Cochard, 1996). However these hardy oaks, which seem to function at the point of xylem dysfunction, are protected from drought-induced embolisms by fine stomatal regulation (Cochard et al, 1996). In drought tolerant forms of *Q. petraea* and *Q. robur* L, a root signaling mechanism is, in part, responsible for stomatal regulation through the release of abscisic acid (ABA) (Triboulot et al, 1996). According to Ridolfi et al (1996), normally, root ABA will induce a stomatal closure, in association with an increase in cytosol-free calcium in the guard cells, which in turn prohibits a proton efflux and K^+ uptake, but promotes an anion efflux. Subsequent swelling results in closure of the stomatal cells. A severe calcium deficiency in a root nutrient solution did not affect stomatal reactivity to ABA, in dark conditions; but during the transition from dark to light there was a slow down in response, and in full light conditions, stomatal closure rates slowed 50% in *Q. rubor* (Ridolfi et al 1996). So under dark shady conditions, ABA released from the roots may be the primary controller, but with an open canopy, calcium is necessary for appropriate stomatal regulation.

Since the majority of fine oak root tips are mycorrhizal in nature, and can affect nutrient uptake, do they then affect the calcium uptake and production of ABA and thus directly influence stomatal closure and drought resistance ? This question cannot be answered here but it is not a far leap to state that the loss of mycorrhizae will have some effect on the metabolic and physiological functioning of the roots and drought resistance. Drought induced loss of normal mycorrhizal flora may, in addition, allow pathogenic invasion. A sharp drop in the ground water levels around the Volga river in southern Russia seems to be associated with secondary oak deaths caused by frost damage and pathogenic fungal invasion (Balder & Liese, 1990). The potential mediators, the mycorrhizae, were not measured.

4-3-3: Drought Induced Sugar Changes

Drought has a pronounced effect on the carbohydrate content of leaves in *Q. petraea* saplings where starch and sucrose declined, but glucose and fructose increased thus maintaining a sugar balance in the leaves and contributing to drought - resisting osmotic adjustments (Épron & Dreyer, 1996). In a similar fashion, starch and sucrose reserves in roots are usually depleted during drought (Wargo, 1981), and the drought stressed roots tend to accumulate four to five times more glucose and fructose (reducing sugars) in their bark than is normal (Wargo, 1971). The increase in glucose is important to the fungus *Armillaria* since this is its preferred sugar source (Garraway, 1974). The glucose not only stimulates rapid growth of *Armillaria* but also enables the fungus to grow in the presence of inhibitory phenols which, when oxidized, actually become a nutrient source for *Armillaria* (Wargo, 1980).

4-3-4: Drought Altered Nitrogen Metabolism

In damaged trees, in N.W. Germany, 150 year old *Q. petraea* and *Q. robur* trees exhibited enhanced winter frost damage in stands with excessive N (low C/N ratio) and preceding insect defoliation (Thomas & Blank, 1996). It was not clear as to which of the factors: high nitrogen, low carbohydrate concentration or insect defoliation had the greatest effect on winter hardiness loss. Besides affecting winter hardiness, changes in nitrogen metabolism can also contribute to fungal invasion. Lytic enzymes (glucanase and chitinase) present in the wood and inner bark of healthy forest tree roots act as nitrogen-based fungal defense mechanisms, but following defoliation the activity of these enzymes is impaired (Wargo, 1975,1976). Stress by defoliation or drought causes increases in other amino nitrogens (alanine, asparagine, and leucine) in the bark and wood of roots (Parker, 1979, Wargo 1972) which can act as a nutritional nitrogen source for the pathogen *Amarillaria* (Wargo, 1984). Nitrogen may be essential for the oxidation of defensive phenols in roots (Wargo, 1984). In healthy trees, phenolic oxidation by fungal oxidative enzymes and pathogen induced necrosis is prevented by a highly reductive state of the phenols, confining the infection sites (Wargo and Montgomery, 1983).

Appendix 4-4: Biotic Factors

4-4-1: Insects:

The biotic factors contributing to decline may include insects (USDA-FS-SR, 1989) such as bark beetles (*Agrilus* spp., *Scolytus* spp.), wood boring insects (*Platypus* spp), and defoliating insects (*Tortix viridana, Tortix* spp.) (Thomas and Hartman, 1996), (*Operophthera brumata)* (Hertel & Zaspel, 1996) and nematodes (*Bursaphelenchus* *fraudulenius*) (Balder, 1989). During, or immediately after a drought, plant tissue may become more attractive and susceptible to insect infestation and reproduction because of chemical changes that attract insects and allow them to detoxify the defense chemicals (Mattson and Haack, 1987, Wargo, 1996). In Europe, the bark borer, *Agrilus biguttatus* Fabr is the dominant insect colonizer of stressed oaks (Hartman and Blank, 1992, 1993). In the United States, a close relative, *Argilus bilineatus* Web plays a similar role (Haak and Blank, 1991). Oddly enough, some trees will compensate for short-term growth losses due to defoliation or drought stress or both by increasing (fruit and girth) productivity for decades after the defoliator outbreaks. (Trumble et al, 1993).

4-4-2: Fungi

Anthracnose is a general term for a set of disease symptoms that affect a wide variety of trees that are attacked by fungi. There are numerous fungal diseases, some specific and localized, and others exotic introductions which tend to spread more quickly due to lack of predators, flora competition, or adequate host control mechanisms. The latter can quickly become endemic leading to wide spread host death especially in monoculture forests, and in today's world potentially epidemic or even pandemic. Necrotrophic fungi typically kill their hosts by blocking or destroying the host's water and nutrient systems with hyphae or specially produced yeast cells or toxins, and subsequently act as saphrotrophs degrading the dead tree (LaessØe & Lincoff, 1998) Dead trees, as standing snags, stumps or downed logs are ecosystems in themselves, providing food and shelter for a succession of microorganisms, insects, arthropods, small animals and plants (Schowalter et al 1992). They are and essential part of the natural nutrient cycle. A diverse community of detritivores (bacteria, fungi, micro and macro arthropods) are instrumental in the initial decomposition of fallen trees, by increasing the wood porosity, water holding capacity, and nutrient availability they create "biological hot spots" of available resources (Schowalter et al, 1992) for other plant species. A few diseases specific to oak will be presented here.

Decline has been associated with defoliation caused by anthracnose (Wargo et al, 1983) and / or powdery mildew (Delatour, 1983) (*Microsphaera alphitoides*) (Balder, 1989).

But, unlike other oaks, *Q. petraeae* is fairly resistant to oak leaf mildew (Schütt et al, 1992, p 433). Certain fungal factors can cause vascular mycosis (*Ophiostoma* or *Ceratocystis*) (Siwecki and Liese, 1991). *Ceratocystis fagacearum* is a systemic american fungus which inhabits the sapwood forming tyloses and gums within the vascular system creating a physiological drought situation effectively robing the upper reaches of moisture resulting in rapid (Minnesota red oak) or slow (white oak) wilting. Unlike windborn spore transmission, the *Ceratocystis fagacearum* soil spore mats attract *Nitidulids*, or picnic beetles which feed upon the sticky spores which adhere to the insects and are thus transmitted to an uninfected tree, especially to fresh wounds during summer pruning or after a storm (USDA-FS-SR, 1989). Fungi normally present in decaying wood can become opportunistic parasites of stressed living tissues causing bark necrosis (*Pezicula* spp., *Fusarium solani),* cankers and sapstain problems (*Diplodia mutila*) (Brasier, 1996) or root rot (*Armillaria* spp. and *Collybia* spp) (Brasier, 1996, Wargo, 1996). Some root pathogens such as *Hypoxylon mediterraneum* (DeNot) Mill, can affect other tissues causing black stomata on stems and bole cankers (Vannini et al, 1996). One of the most common slow butt rots in North America is caused by *Ganoderma lucidus* which causes the rotting roots to become white and spongy resulting in above ground stunting, branch dieback and sparce foliage (USDA-FS-SR, 1989). White spongy root rot was not evident in the samples collected in Merzablen. Some species of *Armillaria* were found in the Merzalben forest, but primarily on buried dead wood or stumps and not living trees (Appendix 2).

4-4-3: *Phytophthora cinnamomi*

Major root pathogens (*Phytophthora cinnamomi* and / or *Collybia fusipes*) contribute to significantly to some local acute or chronic declines (Dreyer & Aussenac, 1996). It has been suggested that the pathogenic fungus *Phytophthora cinnamomi* predisposes a tree to drought stress, rather than the reverse trend typical of secondary insect stress decline of susceptible trees (Wargo, 1996). According to Brasier (1996), one of the most destructive of all root pathogens, the oomycete fungus *Phytophthora cinnamomi,* is associated with the decline of Quercus species *(Q. suber* and *Q. ilex*) in the Mediterranean region, and of *Q. rubor* in France (Marçais et al, 1996). This alien species, probably introduced from

Papua New Guinea in the early 1900's has devastated chestnuts (*Castanea spp.*) in the United States and Europe and now threatens forest and heath communities in Australia and oak forests in the western Mediterranean, and coastal north west Europe. Due to cold winters, spreading into north, central and eastern Europe is less likely, but still possible, especially if there is a continuing warming trend. A global temperature increase of ca 1.5 - 4.5 ^{0} C is predicted to occur by the year 2050 (Pearman, 1988). Such an increase may lead to climatic instability including unseasonable rains and droughts, higher CO2 levels, and increased UV radiation (Brasier, 1996) potentially leading to migration of warm-climate fungi to central, N. and E. Europe increasing the threat of *Phytophthora* invasion.

P. cinnamomi survives mild winters (Marçais et al, 1996) and dry periods either as thick walled chlamydospores or vegetatively, deep in the soil near the sinker roots but otherwise it is difficult to detect in the soil. (Shearer and Tippett, 1989). It spreads via motile biflagellate zoospores in the free water of warm soils, and once within the tree, it attacks, root tips, phloem and cambium tissue (Shearer and Tippett, 1989). Beneficial mycorrhizae would also be lost in its attack upon the root tips. According to Brasier (1996) overt symptoms of *P. cinnamomi* invasion include sudden wilting of crowns in early summer or fall, tarry spots on stems (ink disease), cankers and epicormic shoots. Upon excavation, substantial death of fine feeder roots, especially on thinner drier soils, and bark necrosis of the root collar on deeper larger roots is evident. There is some evidence that it affects host stomatal control by reducing cytokinin production in necrotic fine roots leading to crown symptoms resembling severe drought. (Cahill et al, 1986). It has been suggested that the pathogenic fungus *Phytophthora cinnamomi* predisposes a tree to drought stress, rather than the reverse trend typical of secondary fungal-stress decline (Wargo, 1996) In healthy tree roots " lytic enzymes in the inner bark may dissolve the invading hyphal tips, while gallic acid released from tannin in the bark inhibits the fungus. The fungus cannot grow rapidly (when) the glucose level of the tissue is low and nitrogen is present in a form not readily utilized by the fungus. The root resists attach by the fungus, but then stress occurs... and then death" (Wargo, 1996). The vulnerability of the stands depends upon species composition, stand age, site conditions, intensity, duration and frequency of stress events and the aggressiveness and abundance of native or introduced biotic factors. In the Merzalben forest region under study, there was no overt evidence of classic *P.cinnamomi* symptoms.

4-4-4: *Phytophthora ramorum*

Many oaks in the US are also dying and the causative agents may be fungal (Roach, 2001). In August 2000, it was reported by Michael Coit of the Democratic Press, with typical media flair that a "Godzilla" fungus was spreading quickly across coastal California causing sudden death in young and old live and black oaks. The fungus was transmitted apparently by spores. Once in the tree, the fungus releases enzymes that digest the outer dead and inner living bark layers. The wound tissues oozes a black product that signals damage. The fungal strands move inwards weakening the tree making it vulnerable to other pests. Eventually the fungus reaches the vascular tissues, blocking transport and inducing a rapid die back in the leaves similar to drought. (Coit, 2000). By December, 2001, David Rizzo, a University of California plant pathologist identified and named the new species *Phytophthora ramorum.* The pathogen was found to be a member of the same genus responsible for the Irish potato famine in the mid-1800's and Rizzo and his co-workers speculate that it came to the US from Germany, where it has infected rhododendrons since 1993. It may have arrived with unsuspecting travelers carrying the spores on their hiking boots or camping gear. In the US it seems to be less specific, attacking western oaks such as tan oaks, coast live oaks, black oaks and Shreve's oaks and also susceptible eastern oaks such as pin and red oaks, as well as rhododendrons, huckleberry, honeysuckle, coffeeberry, manzanita, buckeye, big leaf maple, bay laurel, evergreens and madrone. Control of the epidemic in California and Oregon has been limited to cut and burn, quarantines on oak products and other host plants from California and Phosphate injections, which slow but do not halt the disease (Roach, 2001).

4-4-5: Armillaria spp: An Opportunistic Threat

Of the Basidiomycetes, the genus Armillaria contains some of the most devastating oak pathogens in Europe and North America (Delatour, 1983) *A. mellea* is the most frequent species in southern Italy regardless of altitude or climatic zones, and has been associated with healthy or lightly declining trees; however *A. gallica* and *A. tabescens* were more limited in range, and most easily found in seriously declining oak woods (Luisi et al, 1996). There are well over 30 possible species of Armillaria.

Armillaria spp are commonly found on trees subject to bark beetle attacks, and apparently can contribute to mortality (Hartman and Blank, 1993) but are unlikely to be primary causative agents. In the soil, on roots, and woody tissues, *A. mellea* produces diploid cells that form whitish mycelial mats with white, flat arborescent rhizomorphs which are long, and large in diameter in comparison to *A. gallica* which produces a reddish mat and rhizomorphs which are thin, brown, cylindrical and monopodal, with few branches. (Luisi et al, 1996). The morphology of *A. tabescens* is similar to both in that it forms a reddish mat like *A. gallica* and white (but thinner) rhizomorphs like *A. mellea.* (Luisi et al, 1996). In the US, *Armillariellia mellea* has fruiting bodies similar to the European version *Armillaria mellea* but American version produces thin black rhizomorphs that resemble shoe laces growing over top of the subsurface roots. These (Shoestring Root rot) rhizomorphs digest the roots very slowly spreading the necrotism to living areas and overall reduce the vigor of the trees (USDA-FS-SR, 1989). The presence of necrotrophic fruiting bodies in fall makes Armillaria easy to spot and identify.

A thorough examination was not made of these non-ectomycorrhizal species, however in collections of fruiting bodies made in the Merzalben oak study sites, *Armillaria mellea* was plentiful each fall growing in tufts on dead wood and stumps, and considerable evidence of the typical mycelial mats and rhizomorphs were present in the soil samples around the living roots collected. These mats and rhizomorphs were all white. Fruiting bodies of *A. gallica* and *A. tabescens* were not found in the Merzalben site. Of the approximately 30 species of Armillaria that could have been present, only *Armillaria bulbosa, A. mellea*, and *A. ostoyae* were found.

4-4-6: Viral Factors

In rare cases, oak decline may be associated with tertiary viral factors. When extracted, viruses will fail to reproduce themselves in filtered sap solutions but when reapplied to leaves will instigate themselves into the cells, reproduce and kill the cells as they emerge creating white spots where the chloroplast laced cells of the leaves have died, subsequently becoming brown spots in some cases (Levine, 1992). Cryptic double stranded RNA viruses have caused achlorotic lesions the leaves of *Quercus robur* in northern Germany (Büttner and Führling, 1996). They are probably transmitted from tree to tree via the saliva of leaf-eating organisms.

4-4-7: Genetic Factors

Promotion of unsuitable population subsets of *Quercus petraea* through forestry practices may account, in part, for the progressive losses in the "European oak decline" syndrome in the face of loss of natural range, and shifting climatic zones. In the past, sessile and pedunculate oaks accounted for nearly 38% of all tree species in Germany, while today conifers are favored replacement species, limiting oaks to one tenth of their original natural range (Kohlstock, 1993) In addition, with anthropogenic expansion (housing, industry and highway systems) and synergistic pollution, shrinking forests are forming isolated reproductive islands. Dramatically reduced reproductive range lowers the potential for cross-pollination, fertilization and the production of viable genetically diverse offspring. Limited intraspecies genetic diversity can then seriously threaten population adaptability and heterozygous evolution in changing environments,

According to Hertel & Zaspel, (1996), over time, subpopulations predisposed to stress may theoretically have a reduced potential to produce viable gametes; while intermediate or tolerant subpopulations would, respectively, maintain a submaximum, or maximum, gametic diversity and thereby a more favorable general ability to adapt to a changing environmental. As a result, through directional genetic drift, the next generations would approach the structure of the tolerant group. Thus adaptation would occur at the population level, if the selection pressures remained the same as in the preceding generations. So perhaps sudden oak death, although a serious monetary problem, may be essential for evolution of more suitable tree species. " To prevent genetic erosion as a result of (artificial) genetic drift, effective population sizes must be kept high and /or gene flow between populations must be guaranteed in order to promote genetic polymorphism"

(Herzog, 1996). In the simplest terms this would mean maintaining multiple mixed populations in different natural environments and selection regimes. (Don't put all your eggs in one basket).

Information is just beginning to emerge concerning genetic variation of sessile oaks (Herzog, 1996, Ducousso et al, 1996, Hertel & Zaspel, 1996) and their essential mycorrhizae (Haese & Rothe, p.c., Uni Mainz). Their respective economic and ecological importance and the precarious state of general forest decline, should make reproductive and silviculture research, with the goal of genetic conservation a high priority.

4-4-7: Natural & Deliberate Biomass Removal

Fire can be a great cleansing factor eliminating severely infected trees, damaged stands and returning basic nutrients to the deepening soil. But because of the very long recovery times, proximity of homes and lack of adequate burn control, many are loath to use this measure. Instead, typically, foresters worldwide have attempted to selectively clean timber forests of infested debris and infected trees in order to create a clean, safe environment in which their selected species can thrive. Removal of dead wood and debris however, also removes a vital nutrient base that a successful long-term plantation is dependent upon. According to the US Forest Service " impact of biomass removal on ecosystem nutrient reserves has been recognized for a century" (USDA -FS, 2001). Experiments in long-term ecosystem productivity conducted in the Pacific Northwest have determined that " removing biomass and woody debris can affect the site nutrient capital an soil properties" (LTEP, 2001). Cleaning and forest harvesting depletes all nutrients, however the ions of most importance according to the USDA-FS (2001) are nitrogen, phosphorous and calcium. Alternate methods of ensuring a healthy, disease-free forest have included fertilization, liming and promotion of genetically suitable species. In the last half century, mycorrhizal inoculations have also been employed to enhance the growth, health and survivability of oak species.

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Appendix 5: Soil Composition & Acid Weathering

5-1: Major Rock Families

The major igneous rock families include: 1. Calc-alkaline rock family which consists of plagioclase, potassium feldspars, quartz, mica, amphibole and pyroxine and are classified together because of their high calcium and alkalie (Na & K) content; 2. Mafic family which consists of two types of rock with many gradations, the alkali-olivine basalts, and tholeiites (higher in Fe and lower in Al than the previous types) and 3. Alkaline rock family which includes the Na and K rich fledspars, feldspathoids, and biotite all lacking silica (Press & Siever, 1985, p 392). All of these can be weathered to form silicate sands, clays and salts, all of which can be eroded to provide the basis for sedimentary deposits and weathered to release lithic plant nutrients.

Appendix Chart 5-1:

Approximate % composition of some minerals found in granite and basalt (Wedepohl, 1967) and other stone types (Schaefer and Schachtschabel, 1978). A more complete listing is available in Fragstein (1982) and Scheffer and Schachtschabel (1978).

	Granite	Basalt	Orthoclase	Plagioclase	Muskovit	Biotite	Pyroxene	Amphibole	Olivine
$SiKO_2$	73%	50%	65%	57%	46%	38%	47%	44%	41%
Al_2O_3	**14%**	**15%**	**19%**	**26%**	**34%**	**17%**	**7%**	**12%**	**<1%**
CaO	1%	10%	<1%	8%	<1%	<1%	19%	12%	<1%
MgO	<1%	7%	<1%	<1%	1%	13%	13%	13%	46%
K_2O	5%	1%	10%	1%	9%	8%	<1%	1%	-

5-2: Limestone (Calcium carbonate) Formation

According to Press & Siever (1985, p.314-326), limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) form as sediments in sea water due to the relative abundance of calcium and bicarbonate ions forming a preciptiate in saturated cold waters, supersaturated warmer waters or by biological precipitation (shells), as a result the CaO of oceanic crust is over double (12.3%) that of the weathered continental crust (5.5%). The ocean acts as a sink for atmospheric CO_2 which gets tied up in the calcium storage cycle and deposited as limestone. By similar processes, calcium can form calcium carbonate in saturated fresh water environments by combining with bicarbonate ions:

Formula for the Formation of Calcium carbonate:

$$\mathbf{Ca^{+2} + HCO_3^- \rightarrow CaCO_3 + H^+}$$

5-3: Limestone Weathering

According to Press & Siever (1985), ground limestone (calcite) is extremely soluable in weakly acidic water (subsaturation Ca levels) and when spread on the soil will dissolve and leach within a short time, thus requiring repeated applications. The soil water combines with the calcite ($CaCO_3$) disassociating the molecule into calcium (Ca^{+2}) and carbonate (CO_3^{-2}) ions which can combine with free H^+ ions in the water to transitionally form carbonic acid (H_2CO_3) which can further drive the process, releasing the H^+ ions and forming bicarbonate (HCO_3^-) which can further ionize to form H^+ and carbonate ions (CO_3^{-2}). According to Ulrich (1983), the Calcium carbonate is washed out of acidified soil in the form of Calcium hydrogen carbonate ($Ca(HCO_3)_2$), increasing the hardness quotient of the leached ground water. The overall (unbalanced) chemical reaction for dissolution of calcium carbonate to release the calcium is given below.

Hydration of Calcium Carbonate to release Calcium ions and bicarbonate:

$$\mathbf{H_2O + CaCO_3 \rightarrow Ca(HCO_3)_2 \rightarrow Ca^{+2} + H_2CO_3 \rightarrow Ca^{+2} + 2HCO_3^-}$$

Weathering processes and mineral dissolution can be rapid such as : Ca from limestone, Ca and Mg from dolomite or kiesert, and Ca, Na and K from feldspars. Some mafic silicates will also dissolve, but much more slowly. For example: Iron peroxide ($4FeSiO_3$), weathers very slowly releasing iron oxide (4 FeO(OH)) and silica ($4SiO_4$); and silica quartz (SiO_2) weathers so slowly that it is considered to be insoluble (Press & Siever, 1985, p.110-111).

5-4: Atmospheric CO_2 Contribution to Limestone Formation and Weathering

According to Press & Siever, 1985, p. 108-109), atmospheric CO_2 can contribute to the production of bicarbonate ions which can combine with Ca in saturated ocean water to form limestone precipitates. Conversely, carbonic acid in acid rain, also formed from atmospheric carbon dioxide can contribute to the dissolution of limestone in soil. Atmospheric CO_2 can combine within a drop of water, disassociating the water molecule to form a weak solution of carbonic acid (H_2CO_3) which then can ionize to release H+ ions and bicabonate, making the drop slightly more acidic. The resulting acid rain with its stored carbon dioxide is far less acidic than those formed with sulfur gases to form sulfuric acid but it is enough to weather rocks. The process is reversible depending upon the relative concentration of the ions involved.

Dissociation of Carbondioxide to form Acid Rain:

$$CO_2 + H_2O \leftrightharpoons H_2CO_3 \leftrightharpoons H^+ + HCO_3^- \leftrightharpoons 2H^+ + CO_3^-$$

Formula for the formation of Sulfur-based Acid Rain:

$$SO_2 + H_2O \leftrightharpoons H_2SO_4$$

5-5: Limestone Weathering & pH

Hildebrand and Schack-Kirchner (1990) examined the chemical interactions of dolomite applications within the litter and humus horizons of the soil with respect to the changes in the pH of the macroporous water. In the overlying litter (Ah) layer, Ca and Mg are held via stable bicarbonate bonds and the bathing solution pH averages 6 to 7, but if the pH values drop below 5, the bicarbonate anion becomes unstable bonding with other local complexes releasing some of the Ca and Mg as organic anions which can leach to the lower soil regions along with the water produced contributing to the sink effect and an overall loss of protons to the deeper soil horizons and the ground water.

Stable Calciumbicarbonate forms at pH 6-7:

$$\mathbf{CaCO_3{\cdot}MgCO_3 + H_2O + 2CO_2 \rightarrow Ca(HCO_3)_2 + Mg(HCO_3)_2}$$

Destabilized Carbonate bonds at pH5:

$$\mathbf{Ca(HCO_3)_2 + 2\ HO\text{-}\underset{\underset{R}{|}}{C}{=}O \rightarrow Ca(O\text{-}\underset{\underset{R}{|}}{C}{=}O)_2 + 2\ H_2O\ + 2\ CO_2}$$

5-6: Aluminum Weathering

Press & Siever (1985, p 104-112) stated that iron oxides and aluminum oxides tend to be very stable minerals under weathering conditions. The common feldspar component of granite, orthoclase, which is high in alumium, will form kaolinite when weathered with acidic water releasing H^+ and K^+ ions, silica (SiO_2) and some anions which leach away very easily from the rocks creating fissures and erosions that can promote faster erosion and eventually form kaolinite clay. The aluminum however is still tightly bound. Under extreme weather conditions (heavy tropical rains), kaolinite clay can further dissolve leaving a solid residue of gibbsite (aluminum hydroxide) $Al(OH)_3$ which is a major component of bauxite, a primary source of aluminum for manufacturing. All this is to say that aluminum is not easily soluabilized and leached. Weak carbonic acid in "normal" acid rain does little to contribute to the alumino-silicate weathering process but stronger sulfuric acids promote more rapid, noticeable damage.

Milld Acid Weathering of Aluminum Feldspar to form Kaolinite:

$$\mathbf{2KAlSi_2O_8 + H_2O + 2(H^+ + Cl^-) \rightarrow Al_2O_3{\cdot}2SiO_2{\cdot}2H_2O + 4SiO_2 + 2K^+ + 2Cl^-}$$

5-7: Weathering Reagents

The reagents used by Razzaghe & Robert (1979) to extract Al, Fe, Mg, Si and K from phlogopit are listed here in order of their greatest to least overall mineral-extraction abilities (Chart 5-2). In addition to recording the initial pH, they determined that the final pH generally rose upon weathering in the closed systems.. Stahlberg (1960) determined that K was more readily released from biotit and phlogopit than muskovit or mikroklin when treated with 1N H Cl and that particle size was inversely related to release rate. The production of specific organic acids by microorganisms (bacteria, fungi, lichens and plant root tips) within the microenvironment of the rhizosphere at certain pH levels can, by inference, influence the release of minerals from the soil to the bathing solution. Some rate differences can exist depending upon the rock types and particle size.

Appendix Table 5-3: Acidic Weathering Agents

A. Strong organic acids which operate within the initial pH range of 3.1 to 3.48 had the greatest total average mineral extraction ability (<9.62%) (Oxalsäure = oxalic acid, Citronsäure = citric acid, Weinsäure = tartaric acid, Salicylsäure = salicylic acid)
B. Medium strength organic acids operating from pH 3.35 to pH 3.45 had moderate average extraction abilities (<4.01%) (Chininsäure = quinine , Milchsäure = lactic acid, Malonsäure, Ameisensäure = formic acid)
C. Inorganic acids (HCl, H_2SO_4) operating at pH 3 had an average extraction rate of < 3.53%.
D. Moderate strength organic acids operating from pH 3.35 to pH 3.9 had relatively low mineral-extraction ability (<2.84%) (Äpfelsäure = malic acid, Fumarsäure = fumeric acid, Essigsäure = acetic acid, hydroxybenzoic, Vanillinsäure = vanillic acids)
E. Very Mild acids from pH 3.6 to 6.10 and water (pH unknown) had the lowest average extraction ability (0.5-1.78%) (Bernsteinsäure, Asparaginsäure, Alanin, Buttersäure and water)

Appendix 5: REFERENCES

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Appendix 6: Mycorrhizae and Heavy Metals

6-1: Summary of Literature Review by Jentschke & Godbold (2000)

6-2: Additional Literature Review

6-3: Possible modes of metal exclusion in Ectomycorrhizae

6-4: Possible modes of metal exclusion in Oak Roots

6-1: Summary of Literature Review by Jentschke & Godbold (2000)

In an extensive literature review by Jentschke & Godbold (2000), they stated that there is no doubt that in many cases ectomycorrhizal fungi indeed ameliorate metal stress in their host plants but the ameliorative capacity may depend on the fungal species or strain, the specific metal and its concentration and speciation in the rhizosphere and tree nutrition. Ectomycorrhizal types may exclude metals from the host plant through various possible means including: exudation of organic acids, adsorption, intracellular sequestration or hydrophobic restriction of apoplastic mobility. From their lengthy report selected notes were made with their acknowledgements, but only the citations directly related to Aluminum toxicity are included in the references for this report.

General Notes on Metal Tolerance:

- Some ectomycorrhizae are effective ameliorators and others are not.
  (Hartley et al, 1997, Jones & Hutchison 1986, 1988 ab, Denny & Wilkins 1987a, Jenstschke et al 1999, VanTichelen et al 1999)
- Metal tolerance is specific to the metal and the ectomycorrhizal species.
  (Jones & Hutichson, 1986)
- Heavy metal amelioration by mycorrhizae is best at low concentrations.
  (Jones & Hutchison 1986, Jenstsche et al 1999).
- Metal sorption is a dynamic not a static process and to assume the metals are always in equilibrium is misleading.
- External mycelium may bind more (Zn or Pb) than the hyphal sheath or hartig net
  (Jentschke et al 1991a)

- Mycelium abundance is often related to reduced (Zn, Cd) translocation to the shoot (Copaert & van Asche, 1992,1993)

Cytokinins may play a role in metal tolerance (Pan et al, 1989)

General Notes on Nutrition:

- A fungus can only increase host tolerance if its own tolerance exceeds that of the host
- Improved nutrition may contribute to higher metal tolerance of mycorrhizal plants.
- Proliferation of mycorrhizae into surrounding soil enhances nutrient (N,P) acquisition (Marschner & Dell, 1994, Brandes et al, 1998)
- Rhizosphere pH and N nutrition forms influence mycorrhizal amelioration. (Marschner, 1991)
- Strong localized acidification occurs during N uptake. (Marschner et al 1991)
- H+ efflux from mycorrhizal roots (linked to NH_4^+ uptake) may decline and be taken over by fungal hyphae (Brandes et al 1998)
- Mycorrhizal roots extend more slowly than non-mycorrhizal roots.
- Mycorrhizae may protect meristems if their absorptive capacities exceeds that of the apex.
- The sorptive capacities of individual mycorrhiza depends upon chemical composition of the wall, and thus the fungal species involved (Kapoor & Viraraghavan, 1995)
- Phytohormones produced by some Fungi may indirectly alter plant hormones by improving nutrition. (Gogala, 1991)

General notes on Aluminum:

- Ectomycorrhizae have been demonstrated to alleviate growth depression of tree seedlings due to the toxic effects of Al. (Cumming and Weinstein, 1990a, b; Hentschel et al 1993; Schier and McQuattie 1995,1996), Ni (Jones & Hutchinson, 1986, 1988a), Zn (Brown & Wilkins 1985) and Cd (Jentschke et al 1999).

- Adsorption of Al, Pb, Zn on fungal cells of the hyphal sheath or Hartig net is no stronger than that on host tissues (cf Denny & Wilkins 1987b, Jentsche et al 1991a) however, this may depend upon the plant and fungal symbionts
- Although some intracellular uptake of Al into fungal cells of the fungal sheath (Jentschke et al 1991 b) and binding to polyphosphates in fungal vacuoles (Martin et al 1994) may occur, the highest concentrations of Al were not found in the fungal structures but in the root cortex when adequate techniques were used (Jentschke et al 1991 b)
- Al-PO_4 can be used as a P source by some fungi (Cumming & Weistein, 1990c)
- NO_3^- was less effective than NH_4^+ as a nutrition source for Al tolerant mycorrhizae (Cumming & Weinstein, 1990b)
- Al reduces Ca, and Mg uptake (Marschner, 1991) regardless of whether they are mycorrhizal or not (Hentschel et al, 1993, Schier and McQuattie 1995, 1996)
- Al reduces P uptake in non-mycorrhizal and mycorrhizal seedlings but the results are consistent (Marschner, 1991) or not consistent (Cumming & Weinstein, 1990a)
- Al tolerance associated with organic acids (Jones 1998) extracellular fungal chelation (Gadd, 1993)

General notes on Chelation:

- Metal binding in cell walls (Gadd 1993) and vacuoles is considered to be a tolerance mechanism in fungi (Ross 1993, Jones & Hutichson 1986, Brown & Wilkins 1985, Kapoor & Viraraghavan 1995) and higher plants (Ernst et al 1992).
- Competing cations have differential affinities to bind therefore invitro experiments with single ions cannot respresent the natural ecosystem.
- Cu has a greater binding affinity than Pb (Kapoor & Viraraghavan 1995)
- Most of the biochemical chelating studies have been done on lower fungi (Aspergillis, Penicillum, Rhizopus, Yeast) but not higher basidiomycetes.
- Metal binding depends on fungi. Shoot and leaf metal concentrations do not necessarily reflect the root concentration or health status.

- Once the metals have entered the root apoplast/symplast, fungal control may cease.
- Mycorrhizal roots had little influence over apoplastic binding within Norway spruce seedling roots when compared to non-mycorrhizal roots (Jentschke et al 1998)

Metal translocation to shoots from roots can be affected by many factors including: impared translocation, metal intoxication, reduced water, hormonal status

Problems with Techniques:

- Redistribution of ions may occur in the tissue preparation techniques.
- Cryofixation an freezing, changes P causing it to be mainly associated with K and not Ca (Orlovich and Ashford 1993).
- Al dye tracers may adsorb on chitin and cellulose (Behrmann and Heyser, 1992)
- Mobility should be tested under both wet and dry conditions
- Mycorrhiza exude a range of organic acids (Lapeyrie et al 1987)

Mycorrhiza Species Tested for Metal Tolerance:

- *Hymenoscyphus ericae* strains secreting slime increased Zn tolerance in *Calluna vulgaris* (Denny & Ridge, 1995)
- *Laccaria bicolor* demonstrated Pb sorption on the mycelium but had more Pb in the root cortex than *Paxillus involutus* (Marschner et al,1998)
- *Laccaria proxima* alleviated Ni toxicity in *Betula papyrifera* seedlings at 32 but not 64 μM (Jones & Hutchison 1986)
- *Lactarius hibbardae* alleviated Ni toxicity in *Betula papyrifera* seedlings at 32 but not 64 μM (Jones & Hutchison 1986)
- *Paxillus involutus* ecotypes differentially affect the growth of birch clones at high Zn (Denny & Wilkins 1987a)
- *Paxillus involutus* demonstrated Pb sorption on the mycelium but had less Pb in the root cortex than *Laccaria bicolor* (Marschner et al, 1998)
- *Paxillus involutus* decreased Pb uptake into cortical cells on sand but not in a natural forest humus (Jenstschke et al ,1977)

- *Paxillus involutus* offset Cu-induced inhibition of ammonium uptake in pine seedlings, although growth was not affected (VanTichelen et al, 1999)
- *Paxillus involutus* increased Cd tolerance when P soil content improved (Jentschke et al 1999)
- ***Paxillus invoutus* reduced Al toxicity but without P limitations (Hentschel et al , 193)**
- ***Pisolithus tinctoris / Pinus rigida* seedlings were able to use Al-PO_4 as a P source but non-mycorrhizal seedlings could not. (Cumming Weinstein, 1990c)**
- ***Rhizopogon roseolus* chelates Al with oxalic acid (Ahonen-Jonnarth et al 2000)**
- *Rhizopogon roseolus* (Hydrophobic Ascomycetes) excluded Pb and Zn from pine root cortex and stele (Ashford et al 1988, Turnau, unpublished)
- *Thelephora terrestris* offset Cu-induced inhibition of ammonium uptake in pine seedlings, although growth was not affected (VanTichelen et al, 1999)
- *Scleroderma flavidum* reduced the fraction of Ni exchangeable with Ca in *Betula papyrifera* (Jones et al ,1988)
- *Suillus bovinus,* adapted to high Zn, reduced translocation to *Pinus sylvestris* (Bueking & Heyser, 1994).
- *Suillus luteus* (Hydrophobic Ascomycetes) excluded Pb and Zn from pine root cortex and stele (Ashford et al 1988, Turnau, unpublished)
- ***Suillus variegatus* chelates Al with oxalic acid (Ahonen-Jonnarth et al 2000)**

6-2: Additional Literature Review

1. Donner & Heyser (1986) studied 35 year old spruce growing on acidic soil (pH K Cl 3.7) and compared the Al, Mn, Fe and Zn content of healthy and injured tree roots. There was no discrimination between mycorrhizal types but they were able to determine that:

- non-mycorrhizal roots from injured trees had low Ca/Al ratios but healthy tree roots had high Ca/Al ratios (10-20:1)
- mycorrhizal roots from injured and healthy trees had similar Ca/Al ratios

- non-mycorrhizal roots from injured trees had no signs of Mn, Fe, or Zn toxicity, but healthy trees had higher heavy metal components.
- Mycorrhizal roots of injured trees had high heavy metal content in the cortex but not the mantel and healthy trees had heavy metals in the mantel but not the cortex.

Donner and Heyser (1986) concluded that mycorrhizae could filter the metals Mn, Fe and Zn but not Al, and that in injured trees the excluding function for Al was not operational perhaps due to saturation of the complexing sites thus allowing penetration and accumulation of the metals into the root which can lead to or support injuries. The damage may also be due to the ability of mycorrhizae to accumulate heavy metals.

2. Blaudez et al (2000) examined sporocarps of 39 ectomycorrhizal isolates of *Paxillus involutus, Pisolithus tinctorius, Suillus bovinus, S. luteus,* and *S. variegatus* to determine their invitro tolerance of Cd, Cu, Ni and Zn. There were strong interspecific and intraspecific variations in tolerance but overall, *Paxillus involutus* was more tolerant of Ni and the rest were more tolerant of Cd, Cu and Zn. More significantly, there was no appreciable difference in tolerance in isolated from polluted sites when compared to isolates from non-contaminated areas.

3. In contrast, tolerance to Aluminum tolerance was higher in mycorrhizal isolates from metal-contaminated soils compared to those from non-contaminated soils (Leski et al, 1995, Egerton-Warburton & Griffin 1995).

4. Cairney (1999) in a literature survey of intraspecific variablity found that *Paxillus involutus, Pisolithus sp,* and *Suillus luteus,* all with 10 or more isolates tested by different researchers, showed much variation in their Al sensitivity. A strong correlation between Al insensitivity and metal concentration in the environment from which the isolates were obtained was found for *Pisolithus* and *Suillus* (Leski et al, 1995) but not for *Paxillus* suggesting the latter may have consitutive sensitivity (Rudawski & Leski, 1998)

5. Tam (1995) investigated ectomycorrhizae for Al, Fe, Cu and Zn metal tolerance. *Hymenogaster sp, Scleroderma sp,* and *Pisolithus tinctorius* (with slime) were all tolerant of high Al, Fe, Cu and Zn concentrations (but not Cu, Zn, Cd, Cr, Pb or Hg) while *Cenococcum geophilum and Thelephora terrestris* were not tolerant enough to be recommended for bioremediation.

6. Lestan & Lamar (1996) used pelleted solid subtrates coated with spore and mycelial fragments of lignin degrading basidiomycetes as fungal inocula for bioremediation.

6-3: Possible modes of metal exclusion in Ectomycorrhizae

1. Sorption on / in the external mycelium extensions, cystidia, rhizomorphs
2. Sorption on / in the external hyphal sheath
3. Sorption on / in the medial hyphal sheath
4. Sorption on / in the internal hyphal sheath
5. Sorption on / in the hartig net
6. Sorption in species- specific passive or active combinations of the above
7. Exudation of chelating substances into the soil, hyphal or root apoplast
8. Exudation of phytohormones altering root structure or physiology
9. Exudation of nutrients to metal-fixing soil bacteria
10. Exudation of bound heavy metals from cytosol or membranes
11. Hydrophobicity of fungal sheath reducing apoplastic transport
12. Tight hyphal network over root surface and at interfaces
13. Sequestration in metal-selective membrane pores
14. Sequestration in fungal ATPase membrane structures
15. Symplastic sequestration in Phosphate granules in fungal cytoplasm
16. Symplastic sequestration in fungal vacuoles
17. Symplastic sequestration in fungal DNA
18. Production of hydrophobin proteins in the presence of acidic soil solutions
19. Activation of fungal DNA sequences in metal-rich rhizospheres
20. Displacement of sensitive with tolerant fungal strains

6-4: Possible modes of metal exclusion in Oak Roots

1. Ectomycorrhizal species inhabiting finest root tip rhizosphere
2. Exudation of metal chelators to the soil or fungal apoplast
3. Exudation of nutrients to fungal or bacterial vanguards
4. Exudation of hormones to stimulate colonization by ectomycorrhizae
5. Exudation of H^+ or OH^- ions at select locations
6. Apical and subapical pH control (controlling acid solubilization of metals)
7. Alkalinization of the apical rhizoderm to protect the meristem
8. Intact cuticle over epidermis of non-mycorrhizal roots
9. Intact exodermis with few intercellular gaps
10. Epidermal or endodermal suberization to control apoplastic mass flow
11. Cortical membrane selectivity
12. Sequestration within cell walls or in pectin-rich lamellae
13. Sequestration in Phosphate-rich membranes
14. Active storage in cytoplasmic vacuoles
15. Sequestration or neutralization by organic acids or Phosphate deposits
16. Intact pericycle with Endodermal and Hypodermal suberin wall barriers
17. Strong xylem (lignin-based?) chelaton
18. Storage in heart wood
19. Distal control of root physiology by changes in leaf physiology due to metals
20. Displacement of sensitive with tolerant individuals or subspecies

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Appendix 7: Fluorescence of mycorrhizal oak roots.

The autofluorescence (A) and altered fluorescence in the presence of morin (M) was recorded for each ectomycorrhizal species associated with *Quercus petraea* in the unlimed and limed soils of Merzalben Forest Research Center, Rheinland-Pfalz, Germany. Each species varied in their presence depending upon soil depth, season and soil type (unlimed or limed), but if a species was present, it is represented here. The study was conducted over 2 years (1999 and 2000) with samples taken each spring and fall at various soil depths (0-10 cm, 30-40 cm and 50-60 cm).

Each probe is identified according to the season and year during which it was obtained and in addition each probe was given a unique identification number representing the tree from which it was obtained, forest region and soil depth (i.e.- 7N0-10 was harvested from tree number 7 in 1999 in the unlimed (N) plot from 0-10 cm depth, while 1000K30-40 was harvested from tree 10 in 2000 (00) from the limed (K) plot at 30-40 cm depth). Each forest region and each depth is represented for each season a mycorrhiza was present, but the tree source was randomly chosen due to the intensity of the work and the need for adequately sized samples for mineral analysis.

The mycorrhiza were identified (Section C) and selected tips were cryosection for fluorescent analysis (Section B) so that the samples < 1 mm and > 5 mm from the tip could be compared. For most species, these areas represent heavy mantle (<1 mm) and minimal mantle (>5 mm) coverage of the root tip. Emanating hyphae, cystidia and rhizomorphs were included if present. The fluorescence colors were characterized by the color code provided with this appendix.

The root regions are identified by name. The pericycle often consisted of two cell layers, unless it was very close to the tip at which point only one layer was evident near the meristem. The outer cell layer was the primary barrier to Al infiltration into the stele and is referred to as the endodermis. The root region referred to as the hypodermis and eipdermis were in reality the region of the Hartig Net. It was not possible with this technique to distinguish between the fungal and root wall components and for all intents and purposes the fluorescence will be considered to be the same. It would be interesting one day to look more intensely at the ultrastructure of the Hartig net. The only qualification that will be made here is that if the outer epidermal regions were similar to the mantle and the inner hypodermal regions were similar to the cortex, then it was assumed that the hartig net did not penetrate as deeply.

Fifty mycorrhizal species are characterized with respect to their fluorescence traits and morin reactions. Discussion of the results can be found in Section E of this report and in Appendix 12: "Micrographs for Individual Mycorrhizal Species".

Appendix 7 Key Code for Raw Data Sets

Code	Meaning
S-1999	Spring of the year 1999
F-1999	Fall of the year 1999
S-2000	Spring of the year 2000
F-2000	Fall of the year 2000
Probe	See Probe identification number explanation above

Color Code

A	Autofluorescence
M	Fluorescence after Morin staining
X	No fluorescence
<<	Extremely faint
<	Faint
-	Pale
=	Very Pale
+	Bright
++	Very Bright
*	Specks of yellow or yellow-green
**	Abundant specks of yellow or yellow-green
B	Blue
b	Some blue but also some non-fluorescent areas
BG	Bluish green
BY	Bluish yellow
By	Blue with some yellow areas
BO	Bluish orange
G	Green
g	Some green but also some non-fluorescent areas
GB	Greenish blue
GY	Greenish yellow
Gy	Green with some yellow areas
GO	Greenish orange
Y	Yellow
y	Some yellow but also some non-fluorescent areas
YB	Yellowish blue
YG	Yellowish green
YO	Yellowish orange
O	Orange
o	Some orange but also some non-fluorescent areas
OY	Orangish yellow
Y/G	Inner area yellow / outer area green (or whatever colors indicated)
B/Y	Inner area blue (or whatever color indicated) / outer area yellow
Y-G	Variable Results - Most regions yellow - other areas being green (or whatever colors indicated)
G-Y	Variable Results - Most regions green (or whatever color indicated) - fewer regions are yellow

Appendix 7: Fluorescence of mycorrhizal oak. See Appendix Key for codes.

SUMMARY 1

Amphinema byssoides

Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	BY	Y++	X	X	B-	X	B-	X-Y	B-	Y++	B-	Y-	B-	Y-	X	X	B	Y-
1KA	>5	BY	Y++	X	X	B-	X	B-	X-Y	B-	Y++	B-	Y-	B-	X	X	X	B	X
F-1999	<1	B	Y	X	X	B	X	B	X	X	X	B	X	B	X	Y-	Y+	Y-	Y+
6KA	1	NO TIPS LONGER THAN 4MM																	
Limed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	G	O-	X	B	O	B	O	B	Y	B	O	O	O-Y	B	G	B	G
1000k	>5	B	Y	O-	X	B	X	B	X	B	Y/Y-	X	X	Y	O	G	G	G	G

SUMMARY 2

Boletinus cavipes

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	B	B	B	Y	B/Y	YO	y	YO	y	OY	b	B	b	y-
1N0-10	>5	B	G	X	X	B	B	Y	G	Y	Y+	By	By	By	GY	b-	b	y-	Y/G

Appendix 7: Fluorescence of mycorrhizal oak. See Appendix Key for codes.

SUMMARY 3

Boletus edulis

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Rhizomorph**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	YO	X	X	B	B	B	B	YG-	YG+	O-	O-	O-	O-	YO	G+	YG	G+/y-
100N0-10	>5	B	YO	X	X	B	B	B	B	YG-	YG+	O-	O-	O-	O-	YG	G+	YG	G+/y-
F-2000	<1	B	B-	X	X	B	B-	X	X	X	X	X	X	X	X	OY-	X		
700N0-10	>5	B	Y	X	X	X	X	B	Y	Y/G-	G+	X	X	X	O-	OY-	OY+		
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	O	X	X	B	B	B	B	BY	Y/B	O-	O-	O-	O-	YG=	YG=		
300K0-10	>5	B	O	X	X	B	B	B	B	BY	Y	O-	O	O-	O	YG=	YG		
F-2000	<1	B	Y	O	O	GB	GB	GB	GB	Y-	Y+/Y-	O-	O-	O-	O-	O-	O-		
1000K0-10	>5	B	Y	X	X	GB	GB	GB	GB	Y-	Y+	O-	O-	O-	O-	Y-	Y-		
Unlimed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	YO	X	X	B	B	B	B	YG	Y+	O-	O-	O-	O-	YG	Yg	YG	Yg
200N30-40	>5	B	YO	X	X	B	B	B	B	YG	Y+	O-	O-	O-	O-	YG	Yg	YG	Yg
Limed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y	X	X	B	B	B	B	B	O	O-	YO-	O-	X	OY=	YG=		
100K30-40	>5	B	Y	X	X	B	B	B	B	B	O	O-	YO-	O-	X	OY=	YG=		
Unlimed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	Y	Y	G	G	G	G	YG	Y	G	O	G	O	Y	G/Y	Y-	Y-
1100N50-60	>5	B	Y	Y	Y	G	G	G	G	YG	Y	YG	O	YG	O	Y	G/Y	Y-	Y-

SUMMARY 4

Byssocorticium atrovirens

Unlimed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	y-	y-	O	O	B	B	B	B	B	Y	O	YO	O	YO	B*	G*	B*	G*
1100N30-40	>5	y-	y+	O	O	B	B	B	B	B	Y/B-	O-	YO	O-	O+	X	X/B	X	X/G

Appendix 7: Fluorescence of mycorrhizal oak. See Appendix Key for codes.

SUMMARY 5

Cenococcum geophilum

Unlimed Soil 0-10 cm depth

Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	B	B	B	WB	Y	O	Y	O	Y	O	X	X	X	X
1N0-10	>5	B	Y	X	X	B	B	B	B/Y	Y	OY	Y	OY	Y	OY	X	X	X	X
F-1999	<1	B	Y	O	X	B+	B	B+	B	B+	B	O-	O-	O-	O-	X	X	X	X
8N0-10	>5	B	Y	X	X	B+	B+	B+	B+	B	Y	X	X	X	X	X	X	X	X
S-2000	<1	B	Y	X	X	B+	B+	B+	B+	B	Y	O	O	O	O	X	X	X	X
200N0-10	>5	B	Y	X	X	B+	B+	B+	B+	B	Y	X	O	X	O	X	X	X	X
F-2000	<1	B	G	X	X	X	X	B	B	B	Y	B	O	B	O	X	X	X	X
110N0-10	>5	B	Y	X	X	X	X	B	B	B	OY	B	O	B	O	X	X	X	X
F-2000	<1	YG	YG	X	X	X	X	YG	YG-/Y	YG	YG=	YG+	YG=	YO=	YG=	X	X	X	X
700N0-10	>5	YG	YG	X	X	X	X	G	G	X	Y-	X	Y-	X	Y-	X	X	X	X

Cenococcum geophilum

Limed Soil 0-10 cm depth

Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	O	X	B*	GB	B	G	B	YG/O	OY	YO	OY	YP	YG	X	X	X	X
1k0-10	>5	B	Y	X	X	B	OB	B	OB	YG	BY	YG	O/YO	YG	YG	X	X	X	X
F-1999	<1	SPORES ONLY																	
	>5																		
S-2000	<1	B	Y	X	X	B	B	B	B	B	B-	O-	B	O-	YG	X	X	X	X
100K0-10	>5	B	Y	X	X	B	B	B	B	B	Y-	OY-	O-	OY-	O-	X	X	X	X
F-2000	<1	X/B	X/B	X	X	X	X	B-	B-	B-	B-	X	X	O	Y-	X	X	X	X
1000K0-10	>5	X/B	X/Y	X	X	B-	B-	B-	B-	B-	Y-/B	B-	B-	B-	B-	X	X	X	X

Cenococcum geophilum

Unlimed Soil 30-40 cm depth

Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	B+	B+	B+	B+	B	O-	O=	O=	O=	O=	X	X	X	X
4NA30-40	>5	B	Y	X	X	B	B	B	B	B	Y	O-	O-	O-	O-	X	X	X	X
F-1999	<1	B	Y-	X	X	B	B	B	B	B	Y-	X	X	X	X	X	X	X	X
8N30-40	>5	B	Y-	X	X	B	B	B	B	B	Y-	X	X	X	X	X	X	X	X
S-2000	<1	SPORES ONLY																	
F-2000	<1	G	Y	X	X	X	X	G	G	GY	YG	YG	YG	YG	YG	X	X	X	X
1100N30-40	>5	G	Y	X	X	G	G	G	G	GY	YG	YG	YG	YG	YG	X	X	X	X

Cenococcum geophilum

Limed Soil 30-40 cm depth

Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	G	O	O	B	B	B	B	G	B/Y	O	O	O	O	X	X	X	X
1K30-40	>5	B	Y/B	O	O	B	B	B	B	G	YG	O	YO	O	O	X	X	X	X
F-1999	<1	B	Y=	O-	O-	B	B	B	B	B	B	BO-	O=	BO-	O-	X	X	X	X
10K30-40	>5	B	Y=	O-	O-	B+	B	B	B	B	Y	BO	B	BO-	Y	X	X	X	X
S-2000	<1	B	Y	X	B	B*	G*	B	YG	B/Y	Y	O	Y-	O	Y-	X	X	X	X
100k30-40	>5	B	Y	X	X	B*	Y	B	Y	B	Y	O-	B	O=	B	X	X	X	X
F-2000	<1	B	Y	B	B	B	B	B	B	B	Y*	B	O	BY	O*	X	X*	X	X*
1000K30-40	>5	B	Y	B	B	B	B	B	B	B	Y	B	O	BY	O*	X	X*	X	X*

Appendix 7: Fluorescence of mycorrhizal oak. See Appendix Key for codes.

SUMMARY	5	Continued																		
Cenococcum geophilum																				
Unlimed Soil 50-60 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B	Y	X	X	B+	B+	B+	B+	B+	B/O-	B	O=	O=	O=	X	X	X	X	
5N50-60	>5	B	Y	X	X	B+	B+	B+	B+	B/Y-	O/Y-	O-	O-	O-	O-	X	X	X	X	
F-1999	<1	B	Y	X	X	B	B	B	B	B	B/Y-	B	O-	O-	X	X	X	X	X	
7N50-60	>5	B	Y	X	X	B	B	B	B	B	B/Y-	O	O-	O-	O-	X	X	X	X	
S-2000	<1	SPORES ONLY																		
	>5																			
F-2000	<1	B	Y	X	X	X	X	B	B	B	YG	B	YG	B	YG	X	X	X	X	
700N50-60	>5	B	Y	X	X	X	X	B	B	B	YG	B	YG	B	YG	X	X	X	X	
Cenococcum geophilum																				
Limed Soil 50-60 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B+	Y	B+	X	B+	B+	B+	B+	B+	Y	B+	B	B+	Y	X	X	X	X	
5K50-60	>5	B-	Y	B-	X	B+	B+	B+	B+	B+	Y-	GB	B	GB	Y-	X	X	X	X	
F-1999	<1	B	O	O-	X	B	B	B	B	B	B	B-	B	B	Y	X	X	X	X	
10K50-60	>5	BY	Y	O-	O-	B	B	B	B	B	Y	O-	O-	O-	O	X	X	X	X	
S-2000	<1	B	Y	X	X	B	B	B	B	B	Y-	B	O-	Y-	O-	X	X	X	X	
600K50-60	>5	B	Y	X	X	B	B	B	B	B	Y	YB	BY	YB	B	X	X	X	X	
F-2000	<1	B+	Y	X	X	BG	B	BG	B	BG	Y+G-	B+	YG	BG	O-	X	X	X	X	
1000k50-60	>5	B+	Y	X	X	BG	B	BG	B	BG	Y+G-	BG	YG	BG	O-	X	X	X	X	

Appendix 7: Fluorescence of mycorrhizal oak. See Appendix Key for codes.

SUMMARY 6

Cortinarius armillatus

Unlimed Soil 0-10 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	Y-	Y-	X	X	X	X	B-	B-	YB-	YB-	YB-	YB-	YB-	YB-	YB=	YB-			YB=	YB=
700N0-10	>5	B-	B-	X	X	X	X	B-	B-	YG-	YB-	YG-	YB-	YG-	YB-	YG+	YB-			YG-	YG-
F-2000	<1	B	Y	X	X	X	X	B	B	B	B	B	B	B	B	B	O	O	O	O	O
1100N0-10	>5	B	Y	X	X	B	B	B	B	B	Y+	B	B	B	B	O	YO	O	YO	O	YO
Limed Soil 0-10 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	BG	B	BG	O-	Y-	O-	O-	O-	O-	O-	Y-				
1000K0-10	>5	B	Y	X	X	B	BG	B	BG	O-	Y-	O-	O-	O-	O-	O-	Y-				
Unlimed Soil 30-40 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	Y-	O	X	X	B	B	YG	Y-	YG	Y-	YG	Y-	YG	G-			YG-	G
700N30-40	>5	B-	Y	Y-	O	X	X	B	B	YG	Y+/Y-	YG	Y-	YG	Y-	YG+	GY/G			YG-	G
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y	O	O	O	OY	OY	OG	O	O	O	O
1100N30-40	>5	B	Y	X	X	B	B	B	B	B	Y	O	O	O	OY	OY	OG	O	O	O	O
Limed Soil 30-40 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B-	Y	X	X	X	X	X	B	B-	Y/B	G	B	G	B	G	G+	G	G+		
1000K30-40	>5	B	Y	X	X	X	B	B	B	B	YB	G	B	G	B	G	G+	G	G+		

Appendix 7: Fluorescence of mycorrhizal oak. See Appendix Key for codes.

SUMMARY 7

Cortiarius bolaris

Unlimed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	B	O-	O-	B	B	B	B	B	B	O/BG	O/BG	O/BG	O/BG	O/BG	O/BG		
4NA30-40	>5	B	B	O-	O-	B	B	B	B	B	B	O/BG	O/BG	O/BG	O/BG	O/BG	O/BG		
Limed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	YB	O	X	X	B	B-	B	B-	Y-	Y	B	O	B	O	B	G	B	G
4K30-40	>5	YB	O	X	X	B	B-	B	B-	Y-	Y++	O	O	B	O	X	B-	X	B-
S-1999	<1	B	Y	X	X	B	B	B	B	B	Y	O	Y	O	Y	B	Y		
6KA30-40	>5	B	Y	X	X	B	B	B	B	B	Y	O	Y	O	Y	B	Y		
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y	O	O	O	O	Y-	Y+		
110K30-40	>5	B	Y	X	X	B	B	B	B	B	Y	O	O	O	Y-	O	Y		

Appendix 7: Fluorescence of mycorrhizal oak. See Appendix Key for codes.

SUMMARY 8

Elaphomyces muricatus

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y-	X	X	B	B	B	B	B	O=	B	O=	B-	O=	O/Y	YG		
800N0-10	>5	B	Y-	X	X	B	B	B	B	B	O=	B	O=	B-	O=	O/Y	YG		
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	B	X	O-	B	B	B	B	B	B/Y-	O-	O-/Y-	O-	O-	Y-	O/Y+		
1000K01-0	>5	B	B	X	X	B	B	B	B	B	B/Y-	O-	O-	O-	O-	Y-	O/Y+		
Unlimed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	BG	Y-	BG	Y-	BG	Y-	B	B*	X	X
1000N50-60	>5	B	Y	X	X	B	B	B	B	BG	Y	BG	G	BG	G	BY	B*	X	X
Limed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	YB	X	X	B	B	B	B	B	Y	B	B-	B	B-	OY	YG		
1000K50-60	>5	B	YB	X	X	B	B	B	B	B	Y	B	B-	B	B-	OY	YG		

SUMMARY 9

Fagirhiza arachnoidea

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	B	B	B	B	B	B-	B/Y	G=	G-	G-	GB	G-	G	G	G
700N0-10	>5	B	Y	X	B	B	B	B	B	B-	Y	G=	G	G=	G-	G=	G-	G	G
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B-	B/Y	G=	G-	G=	GB	G=	G	G	G
800K0-10	>5	B	Y	X	X	B	B	B	B	B-	B/Y	G=	G-	GB	G-	G=	G	G	G

Appendix 7: Fluroescence of mycorrhizal oak. See Appendix key for codes.

SUMMARY 10

Fagirhiza cystidiophora

Unlimed Soil 0-10 cm depth																							
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	BG-	Y	BG-	Y-	BG-	Y-	O=	O	O=	O	O	O
1100N0-10	>5	B	Y	X	X	X	B	B	B	BG-	Y	BG-	Y-	BG-	Y-	O=	O	O=	O	O	O
Limed Soil 0-10 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B-	Y	BG	O-	BG	O-	O-	Y=	Y-	YO	O	O
1400K0-10	>5	B	Y	X	X	B	B	B	B	B-	O	BG	O-	BG	O-	O	Y=	Y-	YO	O	O

SUMMARY 11

Fagirhiza fusca

Unlimed Soil 0-10 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y/B	X	X	B	B	B	B	B	Y/B	B-	B-	B-	B-	X	X	X	X
400N0-10	>5	B	Y/B	X	X	B	B	B	B	B	Y/B	B-	B-	B-	B-	X	X	X	X
F-2000	<1	B	B/0	X	X	BG+	B+	BG+	B+	B	Y/B	YO<<	O<<	O<<	O<<	X	X	X	X
1600N0-10	>5	B	B/0	X	X	BG	B+	BG	B+	B	Y/B	YO<<	O<<	YO<<	O<<	X	X	X	X
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-1999	<1	B	Y	X	X	B	B	B	B	YB	Y	O<<	X	O=*	X	X	X	X	X
7KA0-10	>5	B	Y	X	X	B	B	B	B	YB	Y	O<<	YO	O=*	YO	X	B	X	X
S-2000	<1	B	B/O	X	X	BG	B	BG	B	BY	Y	O<<	O=	O<<	O=	X	X	X	X
400K0-10	>5	B	Y	X	X	BG	B	BG	B	BY	Y	O<<	O=	O<<	O=	X	X	X	X
F-2000	<1	B	Y	X	X	B/X	B	B/X	B	B/X	Y	B-	Y-	B-	Y-	X	X	X	X
900K0-10	>5	B	Y	X	X	B	B	B	B	B	Y	B	Y-	B	Y-	X	X	X	X
Unlimed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	BG	BG	BG	BG	B-	Y	O<<	X	O<<	X	B*	B/Y*	B*	Y/B
2NA30-40	>5	B	Y	X	X	BG	BG	BG	BG	B-	Y	O<<	X	O<<	X	B*	B/Y*	B*	Y/B
S-2000	<1	B	Y/B	X	X	B	B	B	B	B	Y	B-	B-	B-	B-	X	X	X	X
200N30-40	>5	B	Y	X	X	B	B	B	B	B	Y	B-	B-	B-	B-	X	X	X	X
Limed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	G=	O=	BG	BG	BG	BG	BY	Y	O-	YO-	O-	YO-	X	X	X	X
2KA0-10	>5	B	Y	X	O=	BG	BG	BG	BG	BY	Y	O-	YO-	O-	YO-	X	B-	X	X
S-2000	<1	B	Y	X	X	B	B	B	B	B	Y	O=	YO=	O=	YO=	X	X	X	X
400K30-40	>5	B	Y	X	X	B	B	B	B	B	Y	O=	OY=	O=	YO=	X	X	X	X

Appendix 7: Fluroescence of mycorrhizal oak. See Appendix key for codes.

SUMMARY 12

Fagirhiza granulosa

Unlimed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	B/Y	X	X	B	YG	B	YG	B-	YG	B-	OY-	OB=	OY-	YG/Y-	YG/Y-
100NA0-10	>5	B	B/Y	X	X	B	YG	B	YG	B-	YG	B-	OY-	OB=	OY-	YG/Y-	YG/Y-
F-2000	<1	B	B	X	X	B	B	B	B	YG-	YG-	YG-	YG-	YG-	YG-	O/Y	YG/Y
1100N0-10	>5	B	Y	B	B	B	B	B	B	YG	YG	YG	YG	YG	YG	O/YG	O+
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-1999	<1	B	YB	X	O-	B	B	B	B	YG=	Y/B	YO-	O=	YO-	O=	YG	G/Y
7KA0-10	>5	B	YB	O-	O-	B	B	B	B	YG=	Y/G	O=	O=	O=	O=	Y/YO	Y/YO
S-2000	<1	B	Y/B	X	X	B	B	B	B	BY=	BY-	BY	BY	O=	O=	YG	YG
100K0-10	>5	B	YB	X	X	B	B	B	B	BY=	BY-	BY	BY	O=	O=	YG	YG
F-2000	<1	B	Y/B	X	X	B	B	B	B	BY=	BY-	BY	BY-	O=	O=	YG	YG
1400K0-10	>5	B	Y	X	X	B	B	B	B	BY=	BY-	BY-	BY-	O=	YO=	Y-/Y	YO/Y
Unlimed Soil 30-40 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	YO/B	X	O-	BG	B-	BG	B-	B-	O-	B-	O-	OB-	O-	YG-	G-
4NA30-40	>5	B	YO/B	X	O-	BG-	B-	BG-	B-	OB-	O-	OB=	O-	OB=	O-	YG-	G=
F-1999	<1	B	B/Y	X	O-	BG	BG	BG	BG	B-	Y/B-	B-	YB-	B-	YB-	Y=	Y/BG-
6NA30-40	>5	B	B/Y	X	O-	BG	BG	BG	BG	B-	Y/B-	B-	YB-	B-	YB-	Y=	Y/BG-
S-2000	<1	B	Y	X	X	BG	BG	BG	BG	YB=	Y-/GB	YB-	GB-	YB=	GB	YG=	GB+
300N30-40	>5	B	Y	X	X	BG	BG	BG	BG	YB=	Y-/GB	YB-	GB-	YB=	GB-	YG=	GB+
F-2000	<1	B	Y	X	O-	BG	BG	BG	BG	YG	YG	YG	YG	YG-	YG	B/YG-	YG-*
1100N30-40	>5	B	Y/B	X	O-	BG	BG	BG	BG	YG-	YG/Y	YG	YG	YG-	YG	B-/YG-	YG-*
Limed Soil 30-40 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y	X	O-	B	B	B	B	B	Y	Y=	Y=	Y=	Y=	YG	YG
400K30-40	>5	B	Y	X	O-	B	B	B	B	B	Y	Y=	Y=	Y=	Y=	YG	YG
F-2000	<1	B	BG/Y	X	X	B	BG	B	BG	Y=	Y=	Y-	YO-	O-	B/YO-	YG	Y+/G-
600K30-40	>5	B	BG/Y	X	O=	B	BG	B	BG	Y=	Y=	Y-	YO-	O-	YO-	YG	Y+/G-
Unlimed Soil 50-60 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	BG	B-	BG	B	OB-	YO=	OB-	OB=	0B-	OB=	Y-	G
3NA50-60	>5	B	Y	X	X	BG	B-	BG	B	OB-	YO=	OB-	OB=	0B-	OB=	YG-	G
S-2000	<1	B	Y	X	X	BG	BG	BG	BG	B-	Y/B	B-	O=	B-	O=	Y-	YO=
500N50-60	>5	B	Y	X	X	BG	BG	BG	BG	B-	Y-	B-	O=	B-	O=	Y-	YO=
F-2000	<1	B	Y/B	X	X	BG	BG	BG	BG	Y=	OY-	Y=	OY=	Y=	OY-	O=	G-*
900N50-60	>5	B	B	X	X	BG	BG	BG	BG	Y=	OY-	Y=	OY=	Y=	UY=	O=	G-*
Limed Soil 50-60 cm depth																	
S-1999	<1	B	Y	X	O-	B	BG	B	BG	YB-	Y-/G	Y=	OY=	Y=	OY=	YG-	G*
5KA50-60	>5	B	Y	X	O-	B	BG	B	BG	YB-	Y-/G	Y=	OY=	Y=	OY=	YG-	G*
F-2000	<1	B	Y+	X	X	YG	B	G	B	YB	Y/B	YG	Y	YG-	Y-	YG	Y-
1000K50-60	>5	B	Y+	X	X	YG	B	G	B	B	Y	YG	Y	YG	Y	YG	Y

Appendix 7: Fluroescence of mycorrhizal oak. See Appendix key for codes.

SUMMARY 13

Fagirhiza setifera

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	Y	O	B	W	B	B	Y	O	B	W	B	W	X	X	Y	Y
1N0-10	>5	B	Y	B	B	B	B	B	B	B	YB	B	B	B	B	Y	Y+	Y	Y+
F-2000	<1	B	OY	X	X	B	B	B	B	B-	Y-	B=	G-	B=	G-	X*	X/OY	X	X/OY
1600N0-10	>5	B	OY	X	X	B	B	B	B	B-	Y-	B=	G-	B=	G=	X*	X/OY	X	X/OY
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	OY	X	X	B	B	B	B	B-	YG	B-	O-	B-	O-	X	X	X	X
1K5-10	>5	B	OY	X	X	B	B	B	B	B-	Y	B-	O-	B-	O-	X	X	X	X
F-2000	<1	B	O	X	O-	B	B	B	B	B-	YB=	OB-	O-	O-	O-	X	X	X	X
1100K0-10	>5	B	O	X	O-	B	B	B	B	B-	YB=	OB-	O-	O-	O-	X	X	X	X
Unlimed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	YO	X	X	B	B	B	B	B-	YG	Y-	YO	Y-	YO	X	X	X	X
300N30-40	>5	B	YO	X	X	B	B	B	B	B-	YG	Y-	YO	Y-	YO	X	X	X	X
F-2000	<1	B	O	X	X	B	B	B	B	B-	Y-	B=	O-	B=	O-	X/Y	OY	X	OY
800N30-40	>5	B	O	X	X	B	B	B	B	B-	Y+	B=	O-	B=	O-	X/Y	OY	X	OY
Limed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	G	X	X	B	G-	B	G-	B-	G-	B-	G-	B-	G-	X	X*	X	X
400K30-40	>5	B	G	X	X	B	G-	B	G-	B-	G-	B-	G-	B-	G	X	X*	X	X
F-2000	<1	B	Y	X	X	B	B	B	B	YB	Y	O-	O-	O-	O-	X	X	X	X
900K30-40	>5	B	Y	X	X	B	B	B	B	YB	Y	O-	O-	O-	O-	X	X	X	X
Unlimed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y	X	O-	B	BG	B	BG	B-	YG	Y-	YO	Y-	YO	X	X*	X	X
200N50-60	>5	B	Y	X	O-	B	BG	B	BG	B-	YG	Y-	YO	Y-	YO	X	X*	X	X
Limed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	O	X	X	B	B	B	Y-/B-	BY-	G-	BY-	O	BY-	BG+	X	X	X	X
400K50-60	>5	B	O	X	X	B	B	B	Y-/B-	BY-	G-	BY-	O	BY-	BG+	X	X	X	X

Appendix 7: Fluroescence of mycorrhizal oak. See Appendix key for codes.

SUMMARY 14

Fagirhiza spinulosa

Unlimed Soil 0-10 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B	O	X	X	B	B	B	B	B-	O	O-	O-	O-	O-	X	X	X	X	
1NA0-10	>5	B	O	X	X	B	B	B	B	B-	O	O-	O-	O-	O-	X	X	X	X	
F-2000	<1	B	BG	X	X	B	B	B	B	B-	YO-	O-	Y	O-	O-	X	X	X	X	
1200N0-10	>5	B	BG	X	X	B	B	B	B	B-	YO-	O-	Y	O-	O-	X	X	X	X	
Limed Soil 0-10 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B	O	X	X	B	B	B	B	B-	Y	O-	O-	O-	O-	X	X/Y-	X	X	
1K0-10	>5	B	O	X	X	B	B	B	B	B-	Y	O-	O-	O-	O-	X	X/Y-	X	X	
S-1999	<1	B	Y	X	X	B-	B	B	B	B-	Y=	O-	O-	O-	O-	Y-	Y-	X	X	
4K0-10	>5	B	Y	X	X	B	B	B	B	B	Y=	O-	O-	O-	O-	Y-	Y-	X	X	
F-2000	<1	B	Y-	O=	O=	O=	O-	O=	O-	O=	O=	O=	O=	O=	O=	Y-	Y-	X	X	DEAD
1000K0-10	>5	B	Y/B	X	X	B	B	B	B	B-	O-	O=	O=	O-	O=	Y-	Y-	X	X	
F-2000	<1	B	B	X	X	B	B	B	B	B-	B	O-	O-	O-	O-	X	X	X	X	
1100K0-10	>5	B	B	X	X	B	B	B	B	B	B	O-	O-	O-	O-	X	X	X	X	
Unlimed Soil 30-40 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
F-2000	<1	B	B/O	X	O-	B	B	B	B	B-	Y	O-	O-	O-	O-	X	X	X	X	
1200N30-40	>5	B	B/O	X	O=	B	B	B	B	B-	Y-	O-	O-	O-	O-	X	X	X	X	
Limed Soil 30-40 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
F-2000	<1	B	Y	B	B	B	B	B	B	B	BY	B	YB	B	B	X	X	X	X	
1100K30-40	>5	NO LONG TIPS																			

SUMMARY 15

Fagirhiza tubulosa

Unlimed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	Y	O	B	B	Y	Y+	B/Y	Y	O	Y	O	Y	O	O	O	O
1N0-10	>5	B	Y	Y	O	B	B	Y	Y	B-	Y	O	Y	O	Y	O	O	O	O
F-2000	<1	B	OY	X	X	B	B	B	B	B-	B-	O=	O=	O=	O=	BY=	YG/B	X	X
700N0-10	>5	B	OY	X	X	B	B	B	R	B-	YB-	O=	O=	O=	O=	BY=	YG/B	X	X

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 16

Genea hispidula

Unlimed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		NOTE
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B	Y	Y-	Y-	B	B	Y-	Y+	O	Y+	O	O	O	O	O	O	B-	B	GOOD
1N0-10	>5	B	Y	Y-	Y-	B	B	Y+	Y+	Y	Y+	O	O	O	O	O	O	B	B	GOOD
F-1999	<1	B	Y-	O<<	O<<	BG+	BG	BG+	BG	B+	Y	O-	O-	O-	O-	O-	OY	O-	X	
8NA0-10	>5	B	Y-	O<<	O<<	BG	BG	BG	BG	B+	Y	O-	O-	O-	O-	O-	OY	O-	X	
S-2000	<1	B	Y	X	X	B	B	B	B	B	Y	O=	X	O=	X	X	X	X	X	POOR
500N0-10	>5	B	Y	X	X	B	B	B	B	B	Y	O=	X	O=	X	X	X	X	X	POOR
F-2000	<1	B	Y	X	X	B	B	B	B	B	B/Y	O=	O-	O=	O-	BY-	YG-	X	X	GOOD
900N0-10	>5	B	Y	X	X	B	B	B	B	B	Y	O=	O-	O=	O-	BY-	YG-	X	X	GOOD
Limed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	Y	OY	O-	O-	B+	B	B+	B	B-	OY=	YO-/B	YO-	YO=/B	YO=	X*/O*	X**	X	X	
1K0-10	>5	Y	OY	O-	O-	B+	B	B+	B	B-	OY	YO	YO+	YO	YO+	X*/G*	X**	X	X	
F-1999	<1	B	Y	X	X	B	B	B	B	B	Y/B	O-	O-	O-	O-	X	X	X	X	
6KA0-10	>5	B	Y	X	X	B	B	B	B	B	Y/B	O-	O-	O-	O-	X	X	X	X	
S-2000	<1	B	Y	X	X	B	BG	B	BG	OY=	Y	Y-	Y-	Y-	Y-	X	X	X	X	
100K0-10	>5	B	Y	X	O-	B	BG	B	BG	B	Y	Y-	Y-	Y-	Y-	X	X	X	X	
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y-/B	O=	O=	O=	O=	X	X	X	X	
900K0-10	>5	B	Y	X	X	B	B	B	B	B	Y+/B	O=	O=	O=	O=	X	X	X	X	
Limed Soil 30-40 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
F-2000	<1	B	Y/B	O	O	O	O	O	O	B	Y/B	B-	B	B-	B/Y*	X	X**	X	X**	
1000K30-40	>5	B	B	O	O	O	O	O	O	B	Y/B	B-	B	B-	B/Y*	X	X*	X	X*	

SUMMARY 17

Genea verrucosa

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B-	Y/B-	X	X	X	X	X/Y-	X/Y	X	X
1000NB0-10	>5	B	Y	X	X	B	B	B	B	B-	Y/B-	X	X	X	X	X/Y-	X/Y	X	X
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B-	Y-	O-	X	O-	X	X/Y	X/Y	X	X
900K0-10	>5	B	Y	X	X	B	B	B	B	B-	Y-	O-	X	O-	X	X/Y	X/Y	X	X

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 18

Inocybe obscurobadia

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	BY	X	X	B	B	B	B	B/Y-	Y	O-	OY	O-	OY	O	Y	O	Y
6NA0-10	>5	B	OY	X	X	B	B	B	B	B/Y-	Y	O-	OY	O-	OY	O	Y	O	Y
S-2000	<1	B	YB	X	X	B	B	B	B	BY	OY-	B-	B-	O-	O-	YO	Y-	YO	Y-
100N0-10	>5	B	YB	X	X	B	B	B	B	B-/Y	OY-	B-	B-	O-	O	YO	Y	YO	Y-
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-1999	<1	B	Y	X	X	B	B	B	B	B	Y	X	Y	X	Y	B	Y	alt.sp?	
7KA0-10	>5	B	Y	X	X	B	B	B	B	B	Y	X	Y	X	Y	B	Y	alt.sp?	
S-2000	<1	B	OY	X	X	B-	B	B-	B	B=	YB=	X	O-	O-	O-	O	OY	O	OY
300K0-10	>5	B	OY	X	X	B-	B	B-	B	B=	YB=	X	O-	O-	O-	O	OY	O	OY

SUMMARY 19

Inocybe appendiculata

Unlimed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	B	X	X	B	B	B	B	YB-	YO-	O=	O-	O=	O-	YG	Y
800N0-10	>5	B	B	X	X	B	B	B	B	YB-	YO-	O=	O-	O=	O-	YG	Y
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y/B	X	X	B	B	B	B	B	Y/B	X	O-	X	O-	B	YG
800K0-10	>5	B	Y/B	X	X	B	B	B	B	B	Y/B	X	O-	X	O-	B	YG

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 20

Laccaria amethystina

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle			
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M		
S-2000	<1	B	Y	X	X	BG-	BG	BG-	BG	B-	GY+/Y-	O<<	O<<	O<<	O<<	Y-/X/Y-	B=		
200N0-10	>5	B	Y	X	X	BG-	BG	BG-	BG	B-	GY+/Y-	O<<	O<<	O<<	O<<	X	B=		
F-2000	<1	B	YBG-	X	X	B	B-	B	B-	B-	G-	O=	G-	O=	G-	G	G+		
700N0-10	>5	B	YBG-	X	X	B	B-	B	B-	B-	G-	O=	G-	O=	G-	G	G+		
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle			
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M		
S-2000	<1	B	Y/B	X	X	B	B	B	B	B-	Y+/O	O=	O-	O=	O=	G-	YG		
200K0-10	>5	B	Y/B	X	X	B	B	B	B	B-	Y+/O	O=	O-	O=	O-	G-	YG		
F-2000	<1	B	Y/B	X	X	B	B	B	B	B=	B	O<<	O-	O<<	O-	Y=	Y+		
800K0-10	>5	B	Y/B	X	X	B	B	B	B	B=	B/Y	O-	O-	O-	O-	Y	Y+		

SUMMARY 21

Lactarius acris

Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y/B	B	O	B	O	BG	Y+	BG	Y+
1100K0-10	>5	B	Y	X	X	B	B	B	B	B	Y/B	B	O	B	O	BG	Y+	BG	Y+
Unlimed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B	O	B	O	B	O	BG	BG	BG	BG
1100N50-60	>5	B	Y	X	X	B	B	B	B	B	Y	B	Y	B	O	BG	BG	BG	BG

SUMMARY 22

Lactarius chrysorrheus

Unlimed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y	X	O-	B	B	B	B	B	Y/O	OY-	O-	OY-	O-	Y	G+
100N0-10	>5	B	Y	X	O-	B	B	B	B	B	YO	OY	O-	OY	O-	Y	G+
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	B	X	O-	B	B	B	B	B	Y/B	O-	Y	O-	Y-	Y-	Y+
200K0-10	>5	B	B	X	O-	B	B	B	B	B	Y/B	O-	Y	O-	Y-	Y-	Y+

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 23

Lactarius pallidus

Unlimed Soil 0-10 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	B	X	X	B	B	B	B	B	B	BG	YG	BG	YG	GB	Y
700N0-10	>5	B	B	X	X	B	B	B	B	B	Y	BG	YO	BG	YO	GB	GB/Y
Limed Soil 0-10 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	BG	BG/YG	X	X	BG	BG/YG	BG	BG/YG	YG/X	YO	YG=	O	YO=	O	G+	G+
1000K0-10	>5	BG	Y/B	X	X/Y-	B	B	B	B/Y	YG/X	O	YG-	X	YG	X	G+	G+
Unlimed Soil 30-40 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	B	B	B	B	B	B	B	Y+	B	Y-	B	Y-	B	Y
1100N30-40	>5	B	Y	B	B	B	B	B	B	B	Y	B	Y-	B	Y-	B	Y
Limed Soil 30-40 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	0=	X	B	B-	B	BY-	B	YO	GO-	YG	G0-	YG	YG-	YG+/Y
800K30-40	>5	B	Y	X	X	B	B-	B	BY-	B	YO	BG	YG	YG-	YG	G-	YG+/Y
Unlimed Soil 50-60 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B+	B+	B+	B+	BG	YG	BG	YG	BG	YG	YG	G
1100N50-60	>5	B	Y	X	X	B+	B+	B+	B+	BG	YG	BG	YG	BG	YG	YG	G

SUMMARY 24

Lactarius rubrocintus

Unlimed Soil 50-60 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	O	X	X	B	B	B	B	YO	Y	O-	G	O-	G/O*	X/Y-	BG*
800N50-60	>5	B	O	X	X	B	B	B	B	YO	Y	O-	G	O-	G/O*	X/Y-	G*
Limed Soil 50-60 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y	B	BG	O-	G	O/Y	Y-/Y*
1400KB50-60	>5	B	O	X	X	B	B	B	B	B	Y	B	BG	O-	G	O/Y	G-/Y-*

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 25

Lactarius subdulcis

Unlimed Soil 0-10 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**NOTE**
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B	O	X	X	B+	B+	B-	B	B=	B/B=	O<<	O<<	O<<	0<<	YG<<	YG	
6NA0-10	>5	B	BO/O-	X	X	B-	B-	B-	B-	B-	B/Y-	O<<	X	O=	O-/O	YG<<	YG	
F-1999	<1	B	Y	X	X	B-	B	B-	B	B-	OY<<	X	G=	X	G=	G-	G<<	
10NA0-10	>5	B	O-	O-	X	B+	B+	B+	B+	B-	Y=/O=	O-	O-	O=	O=	GB	G/Y=	
S-2000	<1	B-	B/OY-	X	X	B-	BG	B-	BG	B-	Y-/YG	G-	O-	O-	YO-	GY/BG	YG	
300N0-10	>5	B=	B/O-	X	X	B-	B	B-	B	B-	B/Y-	G-	O-	O-	YO-	GY/BG	G/O/G	
F-2000	<1	X	B	X	X	X	X	B	G	O	G-	X	O	X	O	Y=	Y+	
700N0-10	>5	B	Y	X	X	X	X	B	G	G-	YG	G-	O	G-	YG-	G*	Y++	
1100N0-10	<1	B	Y	X	X	B	B	B	B	B	Y-	X	O	X	O	OY-	OY/B	
Limed Soil 0-10 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B	OY	X	X	BG	B	BG	B	B/BG	Y+/Y-	O-	O-	O-	O-	YG	YG	
4KA0-10	>5	B	Y	O=	O=	BG-	BG	BG-	BG	BG	Y-/YG	OG-	OG-	OG-	OG-	G	G	
F-1999	<1	B	Y	O=	O=	B-	B-	B-	B-	B-	YO/YB	O-	O-	O-	O-	O/G	Y/YG	
7KA0-10	>5	B	Y	O=	O=	B-	BG	B-	BG	B-	OY	O-	O-	O-	OG	YG	YG	
S-2000	<1	B	Y	O=	O=	B-	B-	B-	B-	B-	B/G	B-	B	B/O	B/O	YG	YG	
400K0-10	>5	B	Y	O=	O=	B-	B-	B-	B-	O-	Y/O	B-	B-/O	O-	O-	YG	YG	
F-2000	<1	B	Y	X	X	B	B	B	B	B-	Y	B=	B-	O=	O-	GY-	G/Y	
1200K0-10	>5	B	Y	X	X	B	B	B	B	B-	Y	O=	O=	O=	O-	G-	G/Y	
Unlimed Soil 30-40 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B	O	X	X	B	B	B	B	B	B/O	BY	OG	GY	GG	G/YG	G	
4NA30-40	>5	B	YO	X	X	B	B	B	B	B	Y	BY	G	BY	GG	G	B/G/Y	
F-1999	<1	B	Y	X	X	B	B	B	B	B-	Y/X	B	B	O-	O-	YG	YG	
10NA30-40	>5	B	Y	X	X	B	B	B	B	B-	Y/X	B	B	O-	O-	YG	YG	
S-2000	<1	B	OY	O-	X	B	B	B	B	B-	OY	O-	Y-	O-	Y-	G/YG	G/YG	
300N30-40	>5	B	Y	O-	X	B	B	B	B	B-	Y	O-	YO	O-	Y-	G/YG	GO	
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y/Y-	G	Y-	G	Y-	GY	G+	
700N30-40	>5	B	Y-	X	X	B	B	B	B	B	Y-	B	Y=	B	Y=	B	G	
Limed Soil 30-40 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**NOTE**
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B	Y	O=	O-	B	B	B	B	B/BG	Y+/Y-	OG-	OG-	OG	OG-	YG	YG	
1K30-40	>5	B	Y	O-	O-	B	B	B	B	B	Y-/B-	O-	O-	O-	O-	G	G	
F-1999	<1	B	Y	O=	O=	B-	B-	B-	B-	B-	Y+/Y-	O-	O-	O-	O-	G/Y	YG-/Y	
7KA30-40	>5	B	Y	O=	O=	B-	B-	B-	B-	B+	Y+/Y-	O-	YO-	O-	O-	G/Y	YG/Y	
S-2000	<1	B	Y	O=	O=	B	B	B	B	B	Y	OY-	Y	OY-	Y	B/Y-	Y	
300K30-40	>5	B	Y	O=	Y-	B-	B-	B-	B-	B	Y/O	B	G	O	G/O	GY	YG	
F-2000	<1	BY	Y	B	B	B	B	B	B	BG	Y	YG	YG	YG	YG	OY	YO/Y	
1100KB30-40	>5	BG	Y	B	B	B	B	B	B	BG	Y	YG	YG	YG-	YG	OY	OY/Y	
F-2000	<1	B	Y	O-	O-	B	B	B	B	O-	Y-	O-	O-	O-	O-	G-	YG	VAR?
800K0-10	>5	B	Y	O-	O-	B	B	B	B	B-/O-	Y-	O-	O-	O-	O-	GY-	YG	VAR?

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 25 continued

Lactarius subdulcis

Unlimed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**			
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M		
S-1999	<1	B-	OY-	X	X	B-	B-	B-	B-	B-	O=/Y-	G-	B-	G-	B-	G/B/Y	Y-		
6NA50-50	>5	B	Y	X	X	B+	B+	B+	B	B	OY	G	B	G	B-	G/BY	B/Y		
F-1999	<1	B	Y	X	X	B	B	B	B	B-	Y	O-	G-	O-	O-	YG-	YG-		
7N50-60	>5	B	Y+	X	X	B	B	B	B	B-	Y+	O-	G-	G-	G-	G-	YG-		
S-2000	<1	B	Y/O	O-	O-	B	B	B	B	B	OY	O/B-	O-	O-	O-	G/Y-	G/Y-		
400N50-60	>5	B	Y/O	O-	O-	B	B	B	B	B	OY	O/B-	O-	O-	O-	G/Y-	G/Y-		
F-2000	<1	B	Y+	B	O	B+	B	B+	B	B	Y	B	B	B	B	OY	YG		
1100N50-60	>5	B	Y+	B	O	B+	B	B+	B	B	Y/B	B	B	B	B	O/OY	YG		
Limed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**			
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M		
S-1999	<1	B-	Y	O=	O=	B-	B	B-	B	B=	O/B	O-*	B/O	O=	O=/G	G-	G/Y+		
4KA50-60	>5	B	Y	O=	O=	B	B	B	B	BY-	O/B	O=	B/O	O=	O=/G	G+	G*		
F-1999	<1	B	Y	O=	O=	B	B	B	BG	B-	O/Y	O=	O=	O=	O=	G-/YG	YG/Y		
7KA50-60	>5	B	Y	O=	O=	BG	BG	BG	BG	YB=	OY/O	O=	O=	O=	O=	G/YG	BY/G/Y		
S-2000	<1	B	Y	O=	O=	B	B	B	B	B=	O-	O=	O=	O-	O-	GB	GY		
200K50-60	>5	B	OY	O=	O=	B	B	B	B	B=	OY/O-	O=	O=*	O-	O-*	GY	YG		
F-2000	<1	B	Y	X	X	B	B	B	B	B=	Y/B/O	X	O-	X	O-	GY	GY		
600K50-60	>5	B	Y	X	X	B	B	B	B	B-	Y-/OY	O-	O-	O-	O-	BY	GY-*		

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for code.

SUMMARY 26

Paxillus involutus

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y	X	X	B	B	B	B	G/Y-	Y++	O-	O-	O-	O-	O-	O-	O-	O-
200N0-10	>5	B	B/Y	X	X	B	B	B	B	G/Y-	Y-	O-	O-	O-	O-	O-	O-	O-	O-
F-2000	<1	B	OY	X	X	B	Y	B	Y	B	Y	B	OY*	B	OY*	OY-	Y*	OY-	YG-
1100N0-10	>5	B	OY	X	X	B	B	B	B	B	B	B	OY*	B	OY*	OY-	Y*	OY-	YG-
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y	O-	O-	BG	B	BG	B	YB	Y-	O-	O-	O-	O-	BG-	Y	YG-	YG-
400K0-10	>5	B	Y	O-	O-	BG	B	BG	B	YB	Y-	O-	O-	O-	O-	BG-	Y	YG-	YG-
F-2000	<1	B	YG	X	X	BG	BG	BG	BG	BG	YG	OB=	OB-	OB-	OB-	BG+	BG-	X	X
1100KB0-10	>5	B	YG	X	X	BG	BG	BG	BG	BG	YG	OB-	OB-	OB-	OB-	BG+	BO/G/YG	X	X
Unlimed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y++	B	Y-	B	Y-	YG-	YG-	YG-	YG-
1100N30-40	>5	B	Y	X	X	B	B	B	B	B	Y++	B	Y-	B	Y-	YG-	YG-	YG-	YG-
Limed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
Unlimed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B/Y	Y	O	Y	O	Y	Y	YG	YG-	YG-
1100N50-60	>5	B	Y	X	X	B	B	B	B	B/Y	Y-	O	Y-	O	Y-	Y	YG	YG-	YG-

SUMMARY 27

Phellodon niger

Unlimed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	B/Y	X	X	YB	YB	YB	YB	YB	OY-	O-	O-	O-	O-	G	YG
800N0-10	>5	B	B/Y	X	X	YB	YB	YB	YB	YB	OY-	O-	O-	O-	O-	G	YG
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y+/Y-	X	X	B	B	B	B	YG	O	O	O+	O	O+	G	G
1000k0-10	>5	B	Y+/Y-	X	X	B	B	B	B	YG	OY+	O	O+	O	O+	G	G

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for code.

SUMMARY 28

Piceirhiza bicolor

Unlimed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	B	X	X	B	B	B	B	B	B-/Y	O	Y-	O-	Y-	X/Y-	X
500N0-10	>5	B	B	X	X	B	B	B	B	B	B+/Y	O-	Y-	O-	Y-	X	X
F-2000	<1	B	Y	X	X	B	B	B	B	O	Y	O-	Y+	YO-	Y+	Y	Y+
700N0-10	>5	B	Y	X	X	B	B	B	B	O	Y	O-	Y+	O-	Y/Y-	Y-	Y+
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	O	X	X	B	B	B	B	YB	Y/O	X	X	X	X	Y=	Y=
100K0-10	>5	B	Y	X	X	B	B	B	B	YB	Y/O	X	X	X	X	Y=	Y=
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y	O=	O=	O=	O=	BY=	B/Y+
1400K0-10	>5	B	Y	X	X	B	B	B	B	B	Y	O=	O=	O=	O=	X/Y-	X/Y+
Unlimed Soil 30-40 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	O	X	X	B	B	B	B	B	G	BY-	G	BY-	G	BY	G
400N30-40	>5	B	B/0*	X	X	B	B	B	B	B	G	O-	G	O-	G	X	X
Limed Soil 30-40 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y	X	X	B	B	B	B	YB	Y	O-	O-	O-	G-	O-	O-
500K30-40	>5	B	Y	X	X	B	B	B	B	YG	Y	O-	O-	O-	G-	O-	O-
Unlimed Soil 50-60 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	YO-	O-	O-	B	B	B	B	B	O-	O-	O-	O-	O-/G-	X	G-
800N50-60	>5	B	YO-	O-	O-	B	B	B	B	B	O-	O-	O-	O-	O-/G-	X	G-
Limed Soil 50-60 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y	O-	O-	O-	O-	BY-	Y-
1100K50-60	>5	B	Y	X	X	B	B	B	B	B	Y	O-	O-	O-	O-	X	X

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for code.

SUMMARY 29

Picerihiza chordata

Unlimed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	Y-	Y-	B	B	B	B/Y	B	YO	B	O	B	O	Y	O-
1N0-10	>5	NO LONG TIPS															
S-2000	<1	B	OY	O=	X	B	B*	B	BG	B-	GY-/Y-	O-	YO-	O-	O-	YG-/Y-/Y	YG
200N0-10	>5	B	OY	O=	X	B	B*	B	BG	B-	Y/Y-	O-	YO-	O-	O-	YG	YG
F-2000	<1	B	Y	X	X	B	B	B	B	B	O	B	O	G	YG	GY	YG
1100N0-10	>5	B	Y	X	X	B	B	B	B	B	O	B	O	G	YG	GY	YG
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	B	B	B	B	B-	Y/YG-/Y	O-	G	O-	G	Y-/GY-	YG
1K0-10	>5	B	Y	X	X	B	B	B	B	B-	Y/YG-/Y	O-	G	O-	G	GY-	YG
S-2000	<1	B	Y	O-	O-	B	B	B	B	B-	O/Y-	O-	O-	O-	O-	GY	YG
400K0-10	>5	B	Y	O-	O-	B	B	B	B	B-	O/Y-	O-	O-	O-	O-	GY	YG
F-2000	<1	B	Y	X	X	B	OY	B	Y	B	Y	O	O+	O	O+	G/Y-	G/Y
1000K0-10	>5	B	Y	X	X	B	OY	B	Y	B	Y	O	O+	O	O+	G/Y-	G/Y
Unlimed Soil 30-40 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	O/B	X	X	B	B	B	B	B-	O-	B-	O=	B-	O=	O	YO
4NA30-40	>5	B	OY/YO	O=	O=	B	B	B	B	B-	Y-/O-	O=	O=	O=	O=	O-	YO
S-2000	<1	B	Y	X	X	B	B	B	B	B-	Y	O-	O-	O-	O-	YG	YG
100N30-40	>5	B	Y	X	X	B	B	B	B	B-	Y/Y-/B	O-	O-	O-	O-	YG	YG
F-2000	<1	B	Y	X	X	B	B	B	B	YG	Y/O	O-	O-	O-	O-	OY-	OY-
1100N30-40	>5	B	Y	X	X	B	B	B	B	YG	Y/O	O-	O-	O-	O-	OY-	OY-
Limed Soil 30-40 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	B	B	B	B	B-	X/Y	O-	O-	O-	YO-	YG-	Y+
2KA30-40	>5	B	Y	X	X	B	B	B	B	B-	X/Y	O-	O-	O-	YO-	YG-	Y+
F-1999	<1	B	Y/O	O-	O-	B	B	B	B	B-	Y+	O-	YO	O-	O-	GY-	YG
8KA30-40	>5	B	Y	O-	O-	B	B	B	B	B-	Y+	O-	YO	O-	O-	GY-	YG
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y	O	Y	O	Y	GY-	GY-
1100K30-40	>5	B	Y+	X	X	B	B	B	B	B	Y+	B	Y-	B	Y-	OY-	GY-
Unlimed Soil 50-60 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	BY	O-	O=	B	B	B	B	B	B/YG	OY-	OY-	OY-	OY-	OY-	OY-
4NA50-60	>5	B	Y	O-	O=	BG	B	BG	B	B	B/Y-	OY-	OY-	OY-	OY-	OY-	OY-
S-2000	<1	B	Y	X	X	B	BG	B	BG	B-	O-	O-	YO	O-	YG	YG	YG-
500N50-60	>5	B	OY/B	X	X	B	B	B	B	B-	O/Y-	O-	YO-	O-	O-	YG	YG-

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for code.

SUMMARY 29 continued

Picerihiza chordata																	
Limed Soil 50-60 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B-	Y	O=	X	B	BG	B	BG	G	G/Y-	O-	O-	O-	O-	YG	YG
1KA50-60	>5	B-	Y/B	O-	O-	B	BG	B	BG	B-/YB	Y/Y-	O-	O-	O-	O-	O/YG	YG
F-1999	<1	B	Y	O-	O-	B	B	B	B	B-	O	O-	O-	O-	O-	GY	YG
10KA50-60	>5	B	Y+	O-	O	B	B	B	B	B-	O	O-	O-	O-	O+	GY	YG
F-2000	<1	B	Y	O-	X	BG	B	BG	B	B-	OY	O-	YO-	O-	YO-	OG	YG*
900K50-60	>5	B-	Y-	X	X	G	G	G	G	B	Y/G	B	G	B	G	OY-	O-

SUMMARY 30

Piceirhiza gelatinosa

Unlimed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y	X	X	B	B	B	B	B	Y	B-	O-	O-	O-	Y-	Y
300N0-10	>5	B	Y	X	X	B	B	B	B	B	Y	B-	O-	O-	O-	Y-	Y
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	B	O-	X	B	B	B	B	B	G-	B	G-	Y-	Y-	Y-	Y
200K0-10	>5	B	B	O-	X	B	B	B	B	B	G-	B	G-	BY-	Y-	Y-	Y

SUMMARY 31

Piceirhiza glutinosa=Elaphomyces sp.

Unlimed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	O-	X	X	B	B	B	B	BG	G/Y	B	B	BY	O-	Y-	OY-
1600NB0-10	>5	B	O-	X	X	B	B	B	B	BG	G/Y	BY	B	BY	O-	Y-	OY-
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y/B	OB-	O-	B-	O-	Y-	G-
1200K0-10	>5	B	Y	X	X	B	B	B	B	B	Y/B	OB-	O-	B-	O-	Y-	G-
Unlimed Soil 30-40 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	B/Y	X	X	B	B	B	B	B	Y	B	O	B	O	BY	YB
1100N30-40	>5	B	B/Y	X	X	B	B	B	B	B	Y	B	O	B	O	BY	YB

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for code.

SUMMARY 32

Piceirhiza guttata

Unlimed Soil 30-40 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	OY	O-	O	B	B	B	B	BG	Y	O-	O-*	O-	O-*	YG-	G*
100n30-40	>5	B	OY	O-	O	B	B	B	B	BG	Y	O-	O-*	O-	O-*	YG	G*
Limed Soil 30-40 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y	X	X	B	B	B	B	Y-	Y+	O-	O-	O-	O-	YG-	YG-
100K30-40	>5	B	Y	X	X	B	B	B	B	Y-	Y+	O-	O-	O-	O-	YG-	YG-

SUMMARY 33

Piceirhiza nigra

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	Y-	Y-	B	B	Y	Y+	B	B	B	B	B	B	B	Y	Y-	Y
1N0-10	>5	B	Y	Y-	Y-	B	B	Y	Y+	B	B	B	B	B	B	B	Y	Y-	Y
S-2000	<1	B	B/Y-	X	X	B	B	B	B	B	B/Y=	O-	O-	O-	O-	Y=	X/Y-		
500N0-10	>5	B	B/Y=	X	X	B	B	B	B	B	G/Y=	O-	O-	O-	O-	Y=	X/Y-		
F-2000	<1	B	Y/B	X	X	B	B	B	B	B-	Y	O-	O-	O-	O-	X/YO	G/X/Y-		
900N0-10	>5	B	Y/B	X	X	B	B	B	B	B-	Y	O-	O-	O-	O-	X/Y=	G/X/Y-		
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	B-	X	X	B	B	B	B	B	B-	O-	O-	O-	O-	O/OY-	Y-	Y-	Y-
1K5-10	>5	B	Y	X	X	B	B	B	B	B	Y/B	O-	O-	O-	O-	Y-	Y-	Y-	Y-
S-2000	<1	B	Y	X	X	B+	B+	B+	B	B	G/Y	O-	O-	O-	O-	X/Y-	X		
400K0-10	>5	B	Y	X	X	B+	B+	B+	B	B	G/Y	O-	O-	O-	O-	X/Y-	X		
F-2000	<1	B	B	X	X	B	B	B	B	B	B	O-	O-/B	O-	Y/Y-	O=	YO-		
900K0-10	>5	B	B	X	X	B	B	B	B	B	B/Y	O-	O-/B	O-	YO/B	O=	YO-		
F-2000	>1	B	OY	X	X	B	BG	B	BG	B	B/Y-	O-	O-	O-	OY-	OY	Y-		
900K0-10	<5	B	OY	X	X	B	BG	B	BG	B	B/Y-	O-	OY-	O-	OY-	X/OY-	Y-		
Unlimed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	O	X	X	B	B	B	B	B	Y	O-	O-	O-	O-	G-	X		
1NA30-40	>5	B	O	X	X	B	B	B	B	B	Y/O	O-	O-	O-	O-	X	YG-		
Limed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	B	B	B	B	GB	Y	O-	O-	O-	O-	X	X		
4KA30-40	>5	B	Y	X	X	B	B	B	B	GB	Y	OB-	O-	OB-	O-	X	X		
Limed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	B	B	B	B	B	Y-	O-	O-	O-	O-	X/Y-	Y-		
2KA50-60	>5	B	Y	X	X	B	B	B	B	B	OY-	O-	O-	O-	O-	X/Y-	Y-		

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for code.

SUMMARY 34

Pseudotomentella tristis

Unlimed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y	O=	O-	O=	O-	BG	YG-
900N0-10	>5	B	T	X	X	B	B	B	B	B	Y	O=	O-	O=	O-	BG	YG-
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B-	O	X	X	X	X	B	B
900K0-10	>5	B	Y	X	X	B	B	B	B	B-	O	X	X	X	X	B	B

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 35

Quercirhiza fibulocystidiata

Unlimed Soil 0-10 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-1999	<1	B	B/OY	X	X	B+	B+	B+	B+	B	B/Y/O	O=	G-	O=	G-	O=	Y-	O-	Y-	O-	Y-
7NA0-10	>5	B	B/OY	X	X	B+	B+	B+	B+	B	B/Y/O	O=	G-	O=	G-	O=	Y-	O-	Y-	O-	Y-
S-2000	<1	B	Y-	X	O-	B+	GB	B+	GB	B	Y	O-	G-	O-	O-	YG/YO-	O-	YO-	O-	YO-	O-
100N0-10	>5	B	Y-	X	O-	B+	GB	B+	GB	B	Y	O-	G=	O-	O-	YG/YO-	O-	YO-	O-	YO-	O-
F-2000	<1	B	B	X	X	B+	B	B+	B	B	B/Y	O=	O=	O=	O=	GO-	YG-	G=	YG=	G=	YG
1600NB0-10	>5	B	B	X	X	B+	B	B+	B	B	B/Y	O=	O=	O=	O=	GO-	YG-	G=	YG=	G=	YG
F-2000	>1	B	Y-	X	X	B+	BY	B+	BY	B	B/O	O=	O=	O=	O=	G=	G+	G=	G+	G=	G=
1200N0-10	<5	B	Y-	X	X	B+	BY	B+	BY	B	B/O	O=	O=	O=	O=	G=	G++	G=	G+	G=	G=
Limed Soil 0-10 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	B+	B+	B+	B+	B	Y/B/Y	O-	O-	O-	O-	OY-	G	OY-	G+	OY-	G
4KA0-10	>5	B	Y	X	X	B+	B+	B+	B+	B	Y/B/Y	O-	O-	O-	O-	OY-	YG	OY-	YG	OY-	YG
F-1999	<1	B	O	X	X	B+	B+	B+	B+	B-	Y	O-	O-	O-	O-	OY-	OY	OY-	OY	OY-	OY
10K0-10	>5	B	O	X	X	B+	B+	B+	B+	B-	Y	O-	O-	O-	O-	OY-	OY	OY-	OY	OY-	OY
S-2000	<1	B	Y	X	X	B+	B+	B+	B+	B	B/Y-/G	O	O-	O	O	YO	YO	YO	YO	YO	YO
300K0-10	>5	B	Y/B	X	X	B+	B+	B+	B+	B	B/Y-/G	O	O-	O	O-	YO	YO	YO	YO	YO	YO
F-2000	<1	B	Y	X	X	B+	B+	B+	B+	B	G	B	G-	B-	G-	YB-	Y=	YB-	Y=	YB	Y-
1000K0-10	>5	B	Y	X	X	B+	B+	B+	B+	B	G	B	G-	B-	G-	YB-	Y=	Y-	Y=	Y=	Y=
Unlimed Soil 30-40 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y-	X	X	B+	B	B+	B	B-	Y-	O=	O=	O=	O=	OY-	YG	OY-	YG	OY-	YG
4NA30-40	>5	B	Y-	X	X	B+	B	B+	B	B-	Y-	O=	O=	O=	O=	OY-	YG	OY-	YG	OY-	YG
S-2000	<1	B	Y	X	O-	B+	BG	B+	BG	B	Y	G-	G+	YG	G+	YG-	G+	G=	YG-	YG-	YG-
100N30-40	>5	B	Y	X	O-	B+.	BG	B+	BG	B	Y	G-	G+	YG	G+	YG-	G+	G=	YG-	YG-	YG-
F-2000	<1	B	Y/O	X	X	B+	B+	B+	B+	B	B/OY	O=	O=	O=	O=	G-	G+	G-	YG-	G-	YG-
1100N30-40	>5	B	Y/O	X	X	B+	B+	B+	B+	B	B/Y	O=	O=	O=	O=	G-	G+	G-	YG-	G-	YG-
F-2000	>1	B	Y-	X	X	B+	BY	B+	BY	B	B/O	O=	O=	O=	O=	G=	G+	G=	G+	G=	G=
1200N30-40	<5	B	Y-	X	X	B+	BY	B+	BY	B	B/O	O=	O=	O=	O=	G=	G++	G=	G+	G=	G=
Limed Soil 30-40 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-1999	<1	B	Y	X	X	B+	B+	B+	B+	B	Y	O-	O-	O-	O-	O-	O-	O-	O-	O	O
8KA30-40	>5	B	Y	X	X	B+	B+	B+	B+	B	O/Y	O-	O-	O-	O-	O-	O-	O-	O-	O	O
S-2000	<1	B	Y	X	X	B+	B+	B+	B+	B	Y	O	O-	O	O-	Y-	YG	Y-	YG	Y-	YG
300K30-40	>5	B	Y	X	X	B+	B+	B+	B+	B	Y	O	O-	O	O-	Y-	YG	Y-	YG	Y-	YG
F-2000	<1	B	Y	X	X	X	Y	B	Y	Y-	Y	Y-	OY	Y-	OY	Y+	Y++	Y+	Y++	Y++	O
1000K30-40	>5	B	Y	O	X	B	B/Y	B	B/Y	B/Y	Y	O	OY	O	OY	Y	Y+	Y	Y+	Y++	O

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 36

Quercirhiza squamosa

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	OB/Y	X	O-	B+	B+	B+	BG	B	OY	O-	O-	O-	O-	X	X	X	X
1NA0-10	>5	B	OB/Y	X	O-	B+	B+	B+	BG	B	OY	O-	O-	O-	O-	X	X	X	X
F-1999	<1	B	B/Y	X	O-	B+	B+	B+	B+	B	O/Y	O-	O-	O-	O-	X	X	X	X
10NA0-10	>5	B	B/Y	X	O-	B+	B+	B+	B+	B	O/Y	O-	O-	O-	O-	X	X	X	X
S-2000	<1	B	O	X	X	B+	BG	B+	BG	B	G	O-	OY-	O-	OY	X	X	X	X
500N0-10	>5	B	O+/B	X	X	B+	BG	B+	BG	B	G/O	O-	OY-	O-	OY	X	X	X	X
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	B-/Y	X	O-	B+	B+	B+	B/G	B	Y0/B	B-	O=	B-	O=	X	X	X	X
1KA0-10	>5	B	B-/Y	X	O-	B+	B+	B+	B/G	B	YB	B-	O=	B-	O=	X	X	X	X
F-1999	<1	B	BY	B	BG	B+	BG	B+	BG	B	O/Y	B	O=	B	O=	X	X	X	X
10KA0-10	>5	B	O/Y	X	X	B+	BG	B+	B	B	Y	B	O=	B	O=	X	X	X	X
F-2000	<1	B	Y	X	X	B	B	B	B	G	O	X	Y=	X	Y=	X	X	X	X
1000k0-10	>5	B	Y	X	X	B	B	B	B	G	O	X	Y=	X	Y=	X	X	X	X
Unlimed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	B+	B+	B+	B+	B	Y	O-	O-	O-	O-	X	X	X	X
2NA30-40	>5	B	Y	X	X	B+	B+	B+	B+	B	Y	O-	O-	O-	O-	X	X	X	X
S-2000	<1	B	O-	X	X	B+	B	B+	B/G	B	Y	G	OY-	O-	OY	X	X	X	X
200N30-40	>5	B	O-	X	X	B+	B	B+	B/G	B	Y	G	OY-	O-	OY	X	X	X	X
F-2000	<1	B	Y	X	O=	B+	BG	B+	BG	B	Y/O	O-	YO*G	O-	YO*G	X	X*	X	X
800N30-40	>5	B	Y	X	O=	B+	BG	B+	BG	B	Y/O	O-	YO*G	O-	YO*G	X	X*	X	X
Limed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	Y	X	X	B+	B+	B+	B+	B	Y	O-	O-	O-	O-	X	X	X	X
1K30-40	>5	B	Y	X	X	B+	B+	B+	B+	B	Y	O-	O-	O-	O-	X	X	X	X
S-2000	<1	B	Y	X	X	B+	B+	B+	B+	B-	Y	O-	OY-	O-	OY-	X	X	X	X
100K30-40	>5	B	Y	X	X	B+	B+	B+	B+	B-	Y	O-	OY-	O-	OY	X	X	X	X
F-2000	<1	B	Y	X	X	B+	B+	B+	B+	B	BY	O-	OB	O-	OB	X	X*	X	X
1400K30-40	>5	B	Y	X	X	B+	B+	B+	B+	B	BY	O-	OB	O-	OB	X	X*	X	X
Unlimed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	OY	B-	O-*	B+	B+	B+	B+	B	OY	O-	O-	O-	YO-	X	X	X	X
6NA50-60	>5	B	OY	B-	O-*	B+	B+	B+	B+	B	OY	O-	O-	O-	YO-	X	X	X	X
S-2000	<1	B	O	X	X	B+	B+	B+	B+	B	YO	O-	OY-	O-	OY	X	X*	X	X
200N50-60	>5	B	OY	X	X	B+	B+	B+	B+	B	YO	O-	OY=	O-	OY=	X	X*	X	X
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y-	B	Y=	B	Y=	X	X	X	X
1100N50-60	>5	B	Y	X	X	B	B	B	B	B	Y-	B	Y=	B	Y=	X	X	X	X

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 37

Quercirhiza sublutea

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		NOTE
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-2000	<1	B	Y	X	X	B	BG	B	BG	B-	B	GO-	BO-	O=	B	OY	YG+	SLOW
500N0-10	>5	B	Y	X	X	B	B	B	B	B-	B/Y-	O=	O-	O=	OY	OY	YG+	SLOW
F-2000	<1	B	Y	X	X	B+	B	X	X	B	Y	B-	OY	B-	OY	O-/G	O/Y-	
1600N0-10	>5	B	Y	X	X	B+	B	B+	B	B	Y	B-	OY	B-	OY	O-/G	O/Y-	
Limed Soil 0-10 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A
S-2000	<1	B	Y	X	X	B	B	B	B	B	Y	O-	O-	O-	O-	YG	YG+	SLOW
400K0-10	>5	B	Y	X	X	B	B	B	B	B	Y	O-	O-	O-	O-	YG	YG+	SLOW
F-2000	<1	B	Y	X	X	B	B	B	B	B	O	O-	Y/0-	O-	Y/O	YG	OY+	
900K0-10	>5	B	Y/B	X	X	B	B	B	B	B	OY/B	O-	BO	O-	BO-	YO-	OG-	

SUMMARY 38

Russula acrifolia

Unlimed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	B/Y-	X	X	B	B	B	B	B	Y-/B	O-	O-	O-	O-	YG	YG=	YG	YG
400N0-10	>5	B	B/Y-	X	X	B	B	B	B	B	Y-/B	O-	O-	O-	O-	YG	YG=	YG	YG
F-2000	<1	B	Y	X	X	B	B	B	B	B-	YB-	O-	O-	O-	O-	G=	YG=	G=	YG=
900N0-10	>5	B	Y	X	X	B	B	B	B	B-	YB-	O-	O-	O-	O-	G=	YG=	G=	YG=
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y-	X	X	B	B	B	B	B-	Y-	X	X	X	X	YG=	BG=	YG=	YG
100K0-10	>5	B	Y-	X	X	B	B	B	B	B-	Y-	X	X	X	X	YG=	BG=	YG=	YG
F-2000	<1	B	O	X	X	B	B	B	B	B-	B-	X	X	X	X	G-	G-	G=	G=
1000K0-10	>5	B	B	X	X	B	B	B	B	B-	B-	X	X	X	X	G-	G-	G=	G=

SUMMARY 39

Russula fuegiana

Unlimed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B-	B	X	X	B-	B-	B-	B-	B-	Y-/B	O-	O-	O-	O-	G++	G+	G++	G+
100N0-10	>5	B-	B	X	X	B-	B	B	B	B	B	O-	O-	O-	O-	G+	G+	G+	G+
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B-	B-	X	X	B-	B-	B-	B-	B-	Y-/B	O-	O-	O-	O-	G+	G+	G+	G+
100K0-10	>5	B-	B-	X	X	B-	B-	B-	B-	B-	Y-/B	O-	O-	O-	O-	G+	G+	G+	G+

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 40

Russula mairei

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y/B	X	X	B	B	B	B	B-	Y/B	OB-	OB-	OB=	OB=	O/G=	G=
100N0-10	>5	B	Y/B	X	X	B	B	B	B	B-	Y/B	OB-	OB-	OB=	OB=	O/G=	G=
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-2000	<1	B	Y	X	X	B	B	B	B	B-	Y-	O=	X	O=	X	X/YG=	X/YG
100K0-10	>5	B	Y	X	X	B	B	B	B	B-	Y-	O=	X	O=	X	X	X/YG

SUMMARY 41

Russula orcheoleuca

Unlimed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	O	X	X	B-	B	B	B	B	B/YO	O-	O+	O-	O+	Y/O	Y+/O
800N0-10	>5	B	O	X	X	B-	B	B	B	B	B/YO	O-	O+	O-	O+	Y/O	Y*O
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	O/B	X	X	B-	B	B	B	B	Y	O-	O+	O-	O+	B/Y	G/YO+
800K0-10	>5	B	O/B	X	X	B-	B	B	B	B	Y	O-	O+	O-	O+	B/Y	G/YO+

SUMMARY 42

Tuber melanosporum

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	B/O	X	X	B	B	B	B	B-	Y/B	O-	YO-	O-	YO-	Y-	YG	Y-	YG
1NA0-10	>5	B	B/O	X	X	B	B	B	B	B-	Y/B	O-	YO-	O-	YO-	Y-	YG/O	Y-	YG/O
F-1999	<1	B	B/Y-	X	X	B	B	B	B	B-	Y/B	O-	O-	O-	O-	O/Y-	G-/Y=	O/Y-	G-/Y=
8NA0-10	>5	B	B/Y-	X	X	B	B	B	B	B-	Y/B	O-	O-	O-	O-	O/Y-	G-/Y=	O/Y-	G-/Y=
S-2000	<1	B	Y/BO	X	O-	B	B	B	B	B	Y*	O-	Y-	O-	Y-	Y-	G-	Y-	G-
400N0-10	>5		Y/BO	X	O-	B	B	B	B	B	Y*	O-	Y-	O-	Y	Y-	G=	Y-	G=
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	O	X	X	B	B	B	B	B-	Y	O-	O-	O-	O-	Y-	YG	Y-	YG
4K0-10	>5	B	O	X	X	B	B	B	B	B-	Y	O-	O-	O-	O-	Y-	YG	Y-	YG
F-1999	<1	B	Y/BO	X	X	B	BG	B	BG	B	B/O	O-	O-	O-	O-	Y-	Y+	Y-	Y+
10K0-10	>5	B	Y/BO	X	X	B	BG	B	BG	B	B/O	BO-	O-	BO-	O-	BY-	Y+/G+	BY-	Y+/G+

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 43

Tuber mesentericum

Unlimed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae		NOTE
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A
F-2000	<1	B	O/B	X	X	B	B	B	B	B-	YO	O-	O	O-	O	YG=	YO-	YG=	YO-	SLOW
900N0-10	>5	B	O/B	X	X	B	B	B	B	B-	YO	O-	O	O-	O	YG-	YO-	YG-	YO-	SLOW
Limed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
F-2000	<1	B	Y+	X	X	B	B	B	B	B-	Y+	O-	O-	O-	O-	BG=	YG	G=	Y=	FAST
800K0-10	>5	B	Y+	X	X	B	B	B	B	B-	Y+	O-	O-	O-	O-	BG=	YG	G=	Y=	FAST

SUMMARY 44

Tuber puberulum

Limed Soil 30-40 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae		Cystidia	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y*	X	X	B	B	B	B	B	Y/Y-	B	Y-	B	GY-	YG-	B/Y	Y+	Y	Y+	Y+
1000K30-40	>5	B	Y*	X	X	B	B	B	B	B+	Y/Y-	B	Y	B	GY	YG-	B/Y	Y+	Y	Y+	Y+

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 45

Tuber rufum

Unlimed Soil 0-10 cm depth																					
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		NOTE	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M		
S-1999	<1	B	O	X	X	B	B	B	GB	B	Y	O-	G=	O-	G=	OY-	G/OY+		
1NA0-10	>5	B	O/B	X	0-	B	B	B	GB	B	Y	O-	G=	O-	G=	OY-	G/OY+		
F-1999	<1	B	Y-	X	X	B+	B	B+	B	GY=	Y+	O-	O-	O-	O-	OG	YG		
7NA0-10	>5	B	Y-	X	X	B+	B	B+	B	GY=	Y+	O-	O-	O-	O-	OG	YG		
S-2000	<1	B	G-	X	X	B	B-	B	B-	BG	G=	O-	O-	O-	O-	O/Y-	OY+	SLOW	
400N0-10	>5	B	B	X	X	B	B-	B	B	BG	G=	O-	O-	O-	O-	O/Y-	OY+	SLOW	
Limed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
S-1999	<1	B	O	X	X	B	B	B	B	B	Y	O-	O-	O-	O-	O-/YG	O-/YG-		
3KA0-10	>5	B	O	X	X	B	B	B	B	B	Y	O-	O-	O-	O-	O-/Y-	O-/YG-		
F-1999	<1	B	YO	X	X	B+	B	B	B	BG	Y+	O-	O-	O-	O-	OG	YG+		
7K0-10	>5	B	YO	X	X	B	B	B	B	BG	Y+	O-	O-	O-	O-	OG	YG+	Y/YG	OY
S-2000	<1	B	Y	X	X	B	B	B	B	BG	Y/B	OY-	O-	OY-	O-	O/GY=	O/Y+	FAST	
100K0-10	>5	B	Y	O-	X	B	B	B	B	B	Y	O-	O-	O-	O-	O/GY=	O/Y+	FAST	
Unlimed Soil 50-60 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B-	B-	B	B	B	Y	B	B	B	B	G	G		
1100N50-60	>5	B	Y	X	X	B-	B-	B	B	B	Y	B	B	B	B	G	G		

SUMMARY 46

Tomentella ferruginea

Unlimed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-1999	<1	B	Y	O-	O-	B	BG	B	BG	YB	Y	OY=	O=	OY=	O=	X	X	X	X
8NA0-10	>5	B	Y	O-	O-	B	BG	B	BG	YB	Y	O=	O=	O=	O=	X	X	X	X
Limed Soil 0-10 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-1999	<1	B	OY	X	X	B	B	B	B	B	Y	X	X	X	X	X	X	X	X
7KA0-10	>5	B	OY	X	X	B	B	B	B	B	Y	X	X	X	X	X	X	X	X
F-2000	<1	B	Y	X	X	B	B	B	B	B	O	Y=	OY	O	OY	X	X	X	X
1000K0-10	>5	B	Y	X	X	B	B	B	B	B	O	Y=	OY	O	OY	X	X	X	X
Limed Soil 50-60 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		Hyphae	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	OY	X	X	B+	B+	B+	B+	O	Y	G	O	G	O	X	X*	X	X
1000K50-60	>5	B-	OY	X	X	B+	B+	B+	B+	O	Y	G	O	G	OG*	X	X*	X	X

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 47

Xerocomus chrysenteron

Unlimed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B	Y	Y-	Y-	B	B	B	B	B	B	Y=	Y=	Y	Y	O	O	OY	OY	
1N0-10	>5	B	Y	Y-	Y-	B	B	BY	Y+	Y-B	X	B	X	B	X	OY	OY-	YO	YO-	
F-1999	<1	B	Y	X	X	B	B	B	B	O	O-	O	O-	O	O-	Y-	Y<<	Y-	Y<<	
12N0-10	>5	B	Y	X	X	B	B	B	B	O	O-	O	O-	O	O-	Y-	Y<<	Y-	Y<<	
S-2000	<1	B	YO	O=	X	B	B-	B	B-	B	Y	O-	O-	O-	O-	Y-	Y=	Y/B	Y-	
500N0-10	>5	B	YO	O=	O=	B	B-	B	B-	B	Y	O-	O-	O-	O-	Y-	Y=	Y/B	Y-	
F-2000	<1	B	G	X	X	X	X	B	G	X	G=	X	X	X	X	Y-	Y+	B	Y-	
700N0-10	>5	B	Y=	X	X	X	X	BG	G	G	G	X	G	X	G	Y	Y++	Y	Y	
Limed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		NOTE
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-1999	<1	B	O	X	X	B	B	B	B	B	Y+/O	O=	O=	O=	O=	Y-	Y=	YG	YG	
4K0-10	>5	B	O	X	X	B	B	B	B	B	Y/0	O=	O=	O=	O=	Y-	Y=	YG-	YG-	
S-2000	<1	B	YO	X	X	B	B	B	B	B	YO	O-	O-	O-	O-	Y-	B/Y	Y-	Y=	slow
400K0-10	>5	B	YO	X	X	B	B	B	B	B	YO	O-	O-	O-	O-	Y=	B/Y	Y=	Y=	slow
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y	Y=	Y=	Y=	Y=	Y=	Y=	B	Y=	
700K0-10	>5	B	Y	X	X	B	B	B	B	B	Y	Y=	Y=	Y=	Y=	Y=	Y=	B	Y=	
Unlimed Soil 30-40 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-2000	<1	B	Y	X	O-	B	B	B	B	B	B/Y	OY-	O	OY-	O	Y-	O	Y-	OY*	
400KB30-40	>5	B	Y	X	X	B	B	B	B	B	Y	OY-	O	OY-	O	Y-	O	Y-	OY*	
Limed Soil 30-40 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-2000	<1	B	O	X	X	B	B	B	B	B	GY=	O-	O-	O-	O-	Y-	Y=	BG-	BG-	
200N30-40	>5	B	O	X	X	B	B	B	B	B	GY=	O-	O-	O-	O-	Y-	Y=	BG-	BG-	
Unlimed Soil 50-60 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
F-2000	<1	B	YO	X	X	B+	BG	B+	BG	B	Y/B	O-	B	O-	B	Y-	Y-	Y-	Y-	
1600N50-60	>5	B	YO	X	X	B+	BG	B+	BG	B	Y/B	O-	B	O-	B	Y-	Y-	Y-	Y-	
Limed Soil 50-60 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y-	O-	B-	O-	B-	Y-	BG-/BY-	Y-	Y-	
1100KG50-60	>5	B	Y	X	X	B	B	B	B	B	Y-	O-	B-	O-	B-	Y-	BG-/BY-	Y-	Y-	

Appendix 7: Fluorescence of mycorrhizal oak roots. See Appendix key for codes.

SUMMARY 48

Xerocomus submentosus

Unlimed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		Mantle		**NOTE**
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-2000	<1	B	B	X	X	B	B	B	B	B	B	O+	O	O+	O	O++	Y+	SLOW
100N0-10	>5	B	B	X	X	B	B	B	B	B	B	O+	O	O+	O	O++	Y+	SLOW
Limed Soil 0-10 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	
S-2000	<1	B	B	X	X	B	B	B	B	B	O/B	O+	O+	O+	O+	O++	Y/Y-*G	
400K0-10	>5	B	B	X	X	B	B	B	B	B	O/B	O+	O+	O+	O+	O++	Y+*G	

SUMMARY 49

Unknown Gray

Unlimed Soil 0-10 cm depth																		
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B	Y	B=	X	B=	X	G	YG
800N0-10	>5	B	Y	X	X	B	B	B	B	B	Y	B=	X	B=	X	G	YG
Limed Soil 0-10 cm depth																	
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	B	B	B	B-	G/Y	X	X	X	X	G	YG
1000K0-10	>5	B	Y	X	X	B	B	B	B	B-	G/Y	X	X	X	X	G	YG

SUMMARY 50

Unknown Rosa

Unlimed Soil 0-10 cm depth																				
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B	YO	Y=/B	Y+/B	B	Y	B	YO	B	YO	X	X	X	X
1100N0-10	>5	B	Y	X	X	B	YO	Y=/B	Y+/B	B	Y	Y	YO	B	YO	X	X	X	X
Unlimed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	Y	X	X	B+	B+	B	B	B	Y+	O	Y-	O	Y-	X	X	X	X
1000N30-40	>5	B	Y	O	X	B+	B+	B	B	B	Y+	O	Y-	O	Y-	B	B	X	X
Limed Soil 30-40 cm depth																			
Season	Tip	Xylem		Phloem		Pericycle		Endoderm		Cortex		Hypoderm		Epiderm		**Mantle**		**Hyphae**	
Probe	mm	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M	A	M
F-2000	<1	B	B	O-	X	B	B	B	B	B/Y	YG	Y=	O	Y=	O	X	X	X	X*YO
1000K30-40	>5	B	Y	O-	X	B	B	B	B	B	Y	Y=	O	Y=	O	X	X	X	X*Y

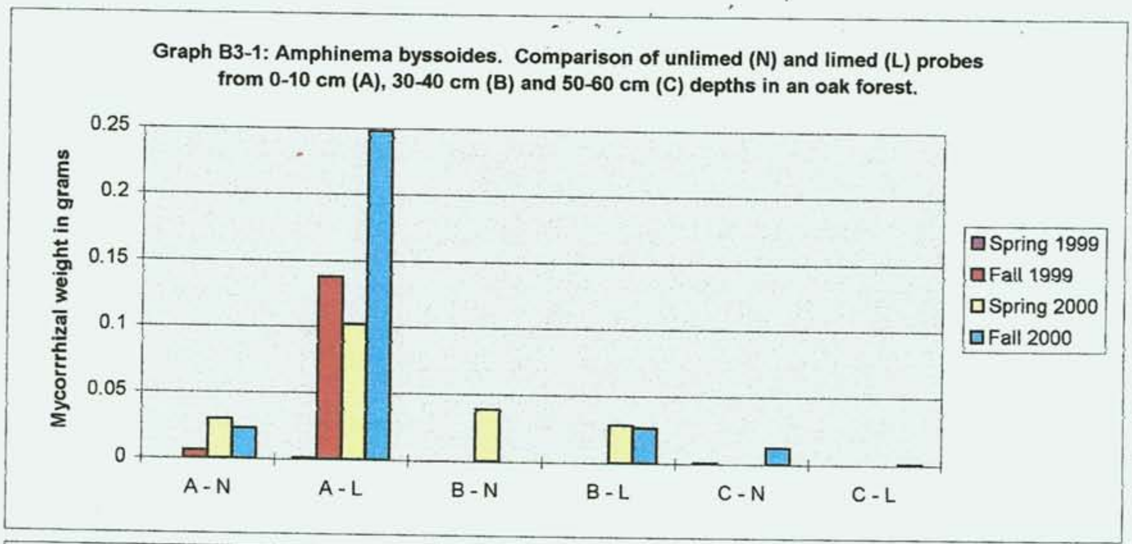
Appendix 8: Mycorrhizal Diversity and Abundance in Limed and Unlimed Soils

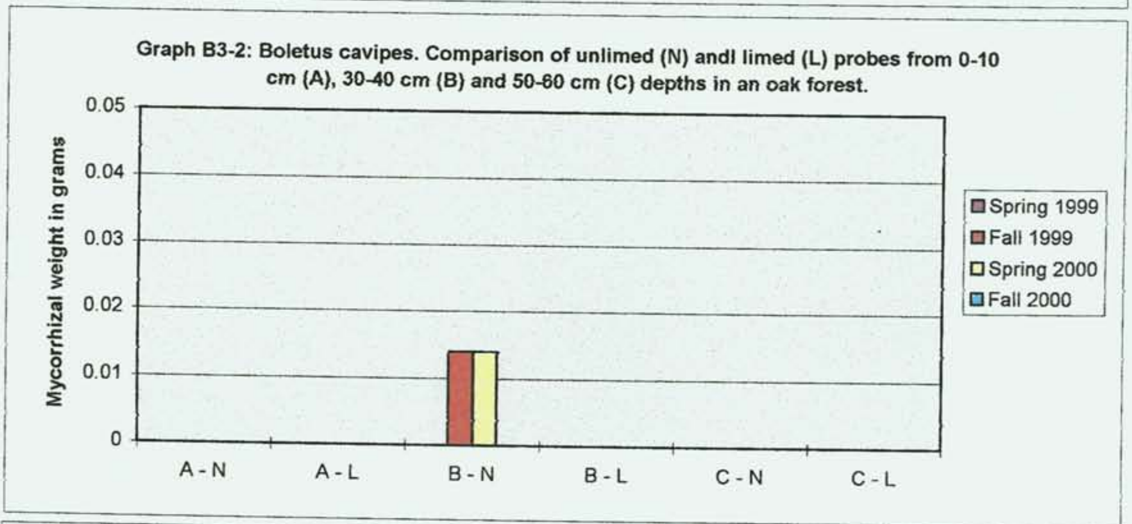
Materials and methods for the following data sets are presented in Section B of this report. Mycorrhizal species were isolated from various soil depths in the unlimed and lime oak forest regions during the spring and fall of 1999 and 2000. Each season, six trees in each zone were selected and sampled for a total of 24 individual trees, 12 in the limed and 12 in the unlimed. The procedure was repeated the following year using the same tree sets. The mycorrhizae isolated from each probe were cleaned, identified and weighed and stored separately in epindorf caplets. The data sets for the spring were amalgamated according to soil depth for each geographic location.

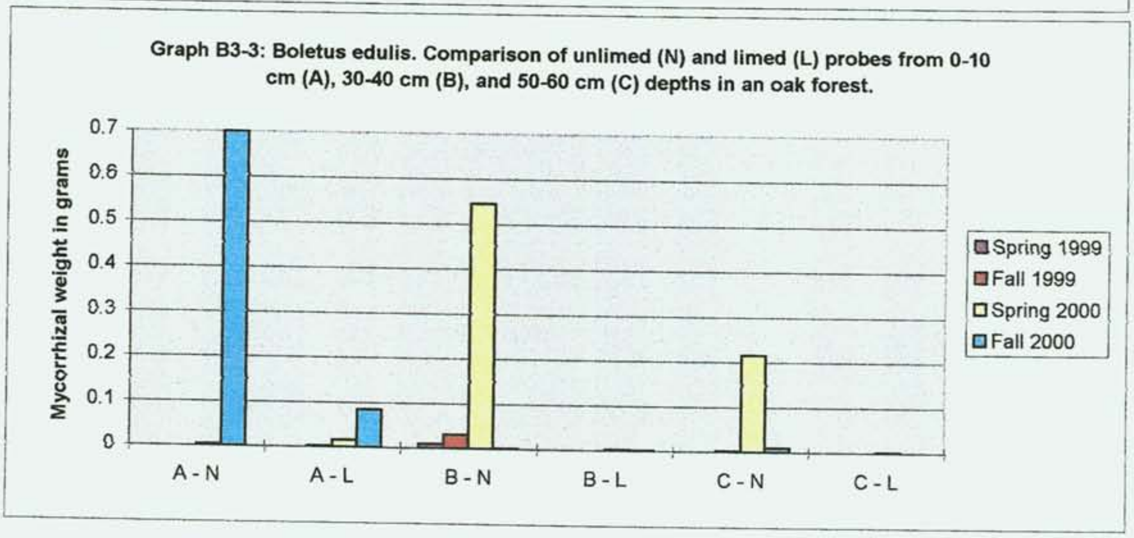
Appendix 8A:
Where there was comparative value, the data has been presented in Appendix 8A: Graphs B3-1 to B3-68, for 68 of the species isolated. The graphs were created to emphasis the species-specific similarities and differences between the unlimed and limed zones. The results are discussed in Section B of this report and incorporated in the last Appendix: Mycorrhizal Micrographs.

Appendix 8B:
The numerical data sets are presented in Appendix 8B which contains 93 Tables, in alphabetical order, of all the mycorrhizae isolated, including unkowns. Of these, only the 50 most prominent species were selected for the fluorescence analysis presented in Appendix 7. Species were eliminated from the study if there was inadequate sample size, dubious characteristics, or no comparative value. All the isolates are presented here to emphasize the point that mycorrhizal diversity in the oak forests is enormous and not limited to the species selected for this study.

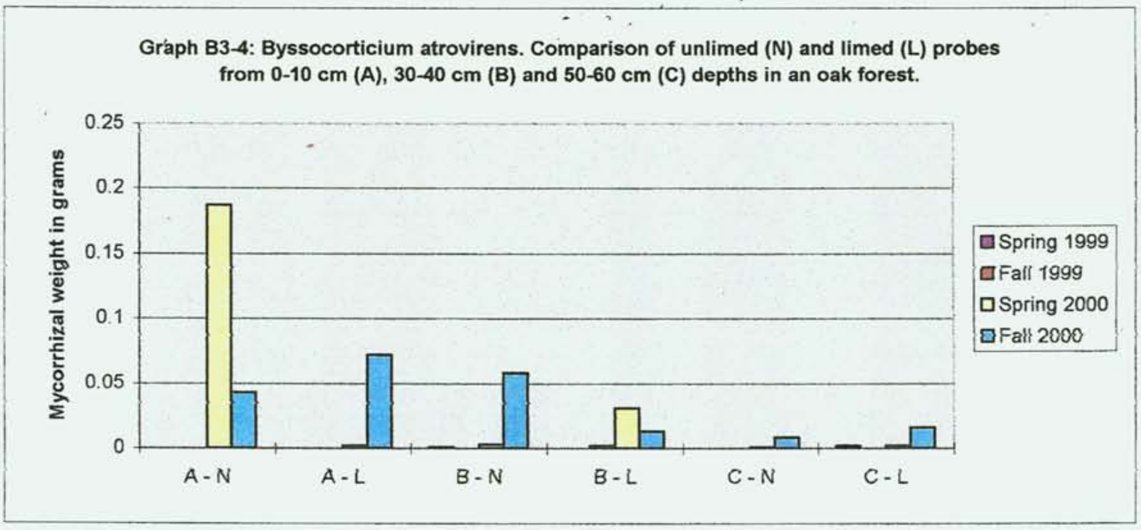
Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

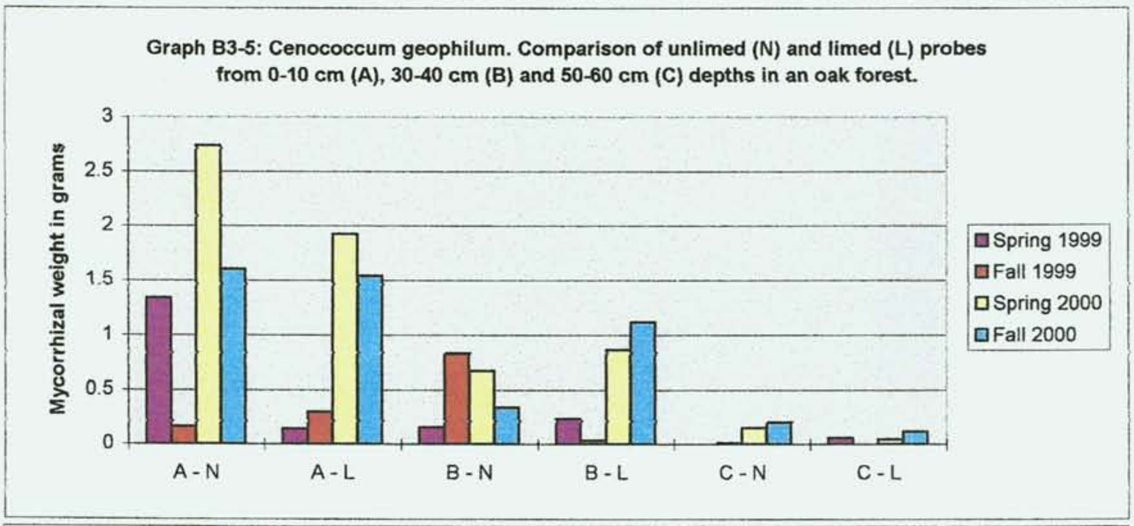


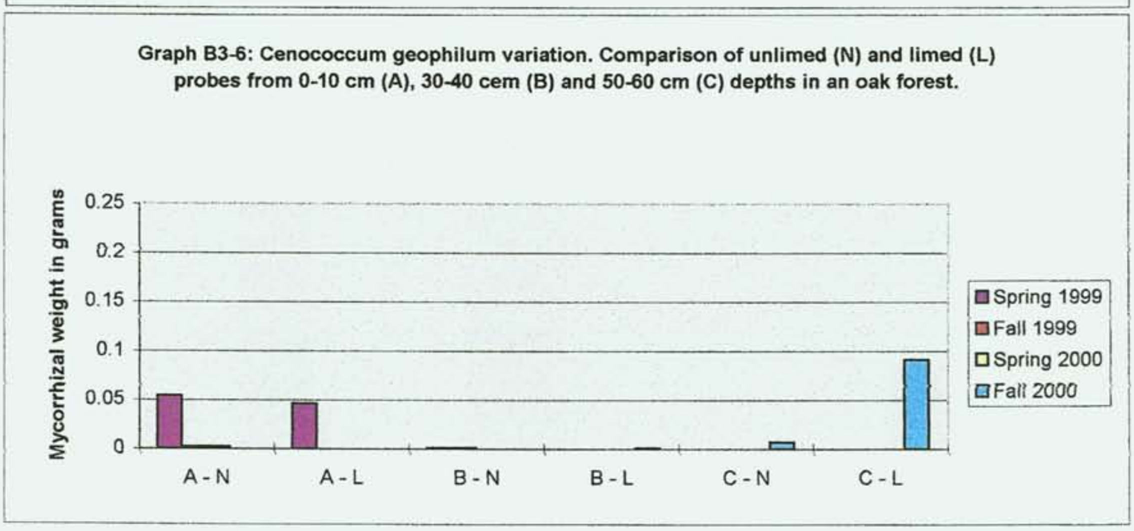




Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

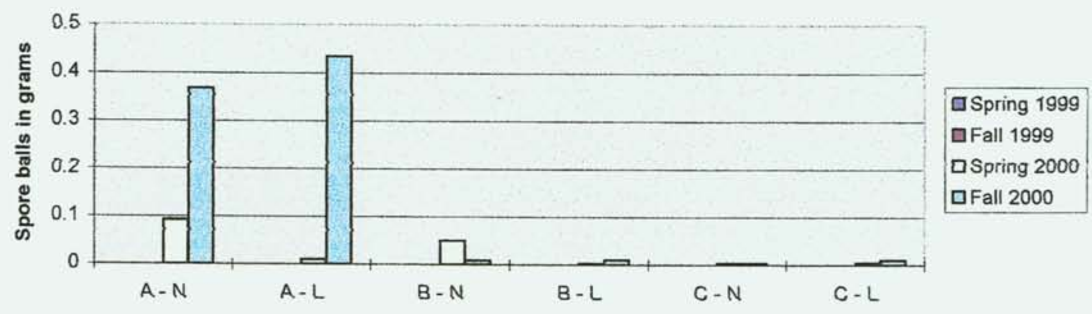




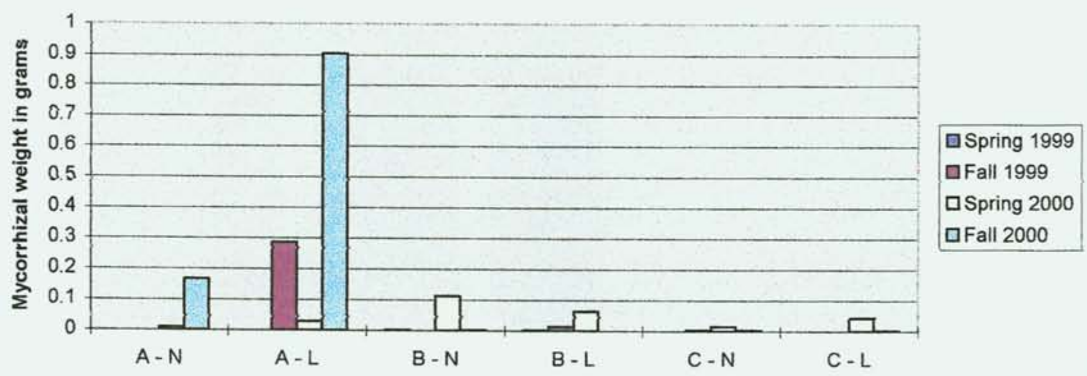


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland Pfalz, Germany

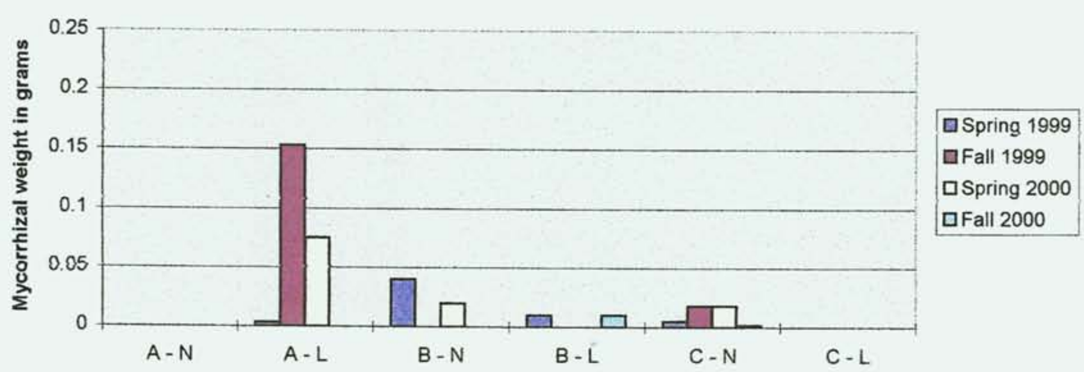
Graph B3-7: Cenococcum geophilum spore balls. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), 50-60 cm (C) depth in an oak forest.



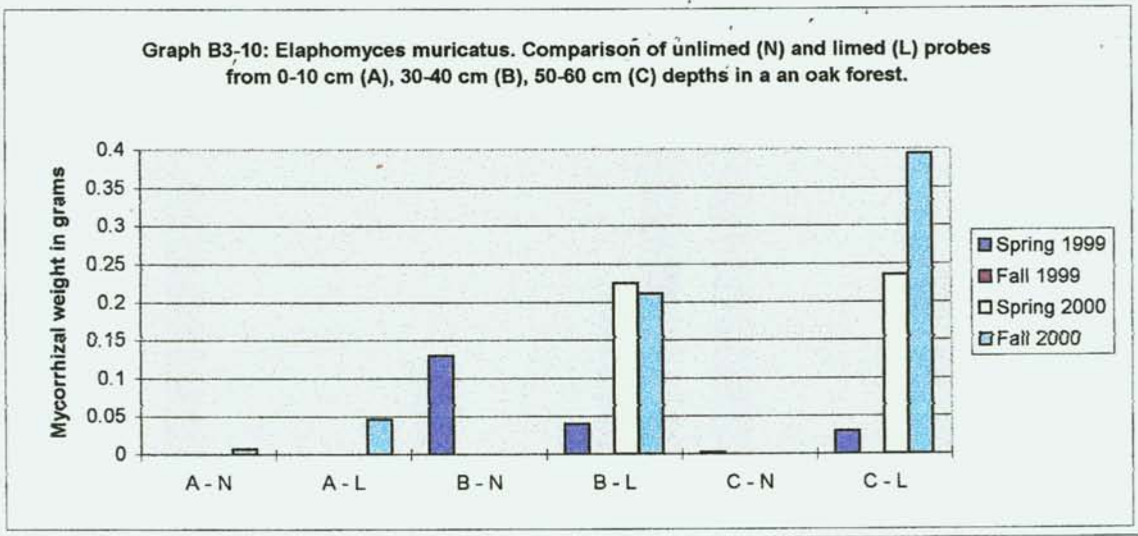
Graph B3-8: Cortinarius armillatus. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depth in an oak forest.

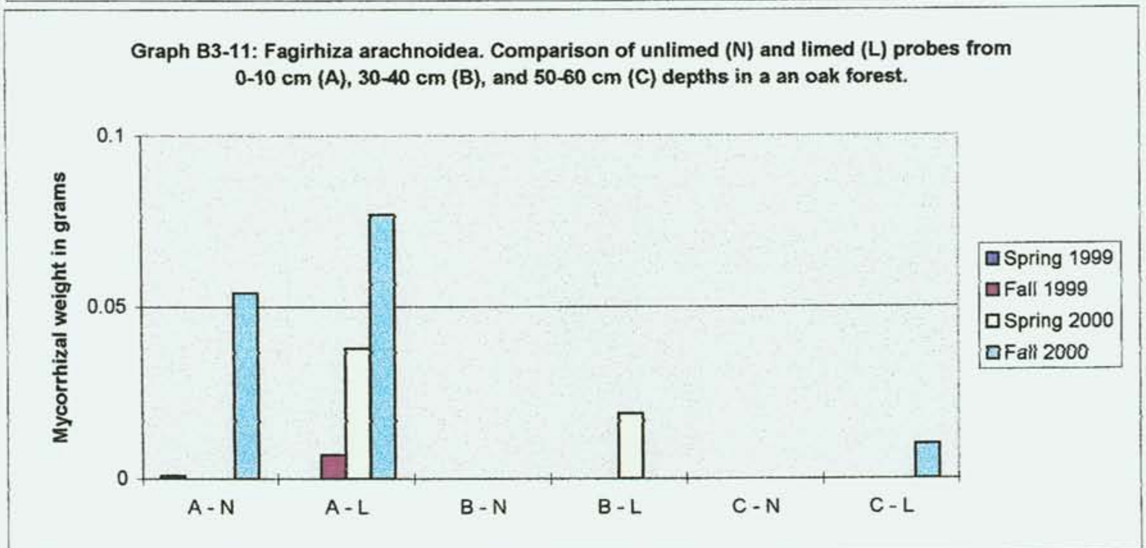


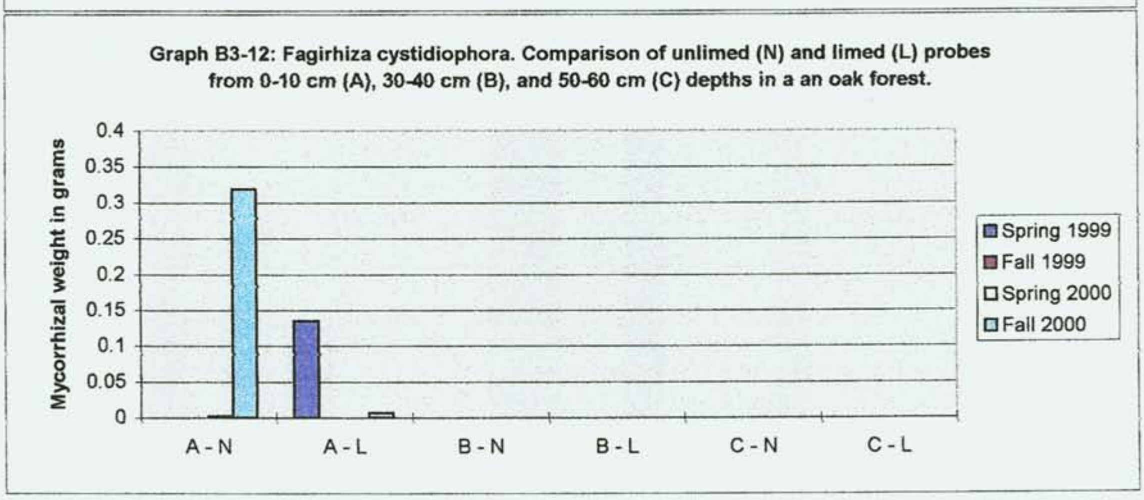
Graph B3-9: Cortinarius bolaris. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth in an oak forest.



Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

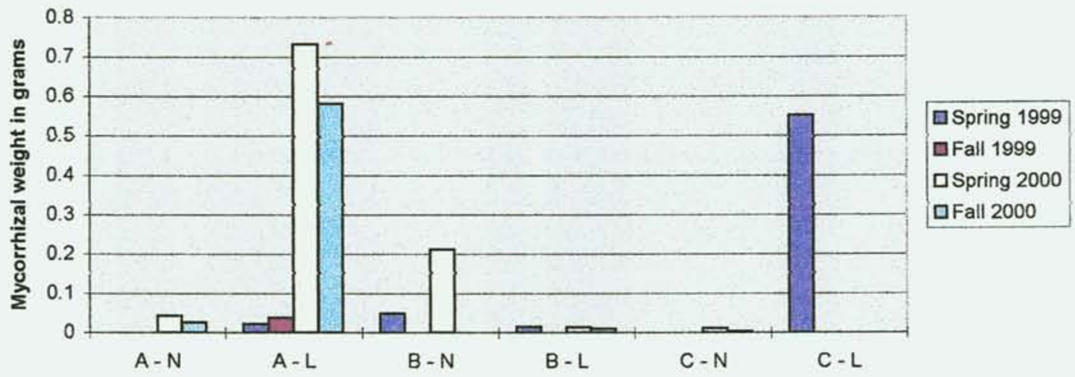




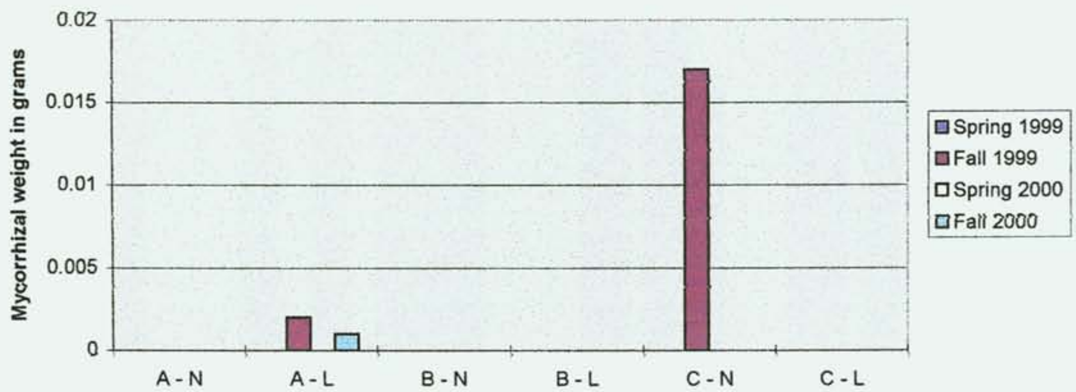


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

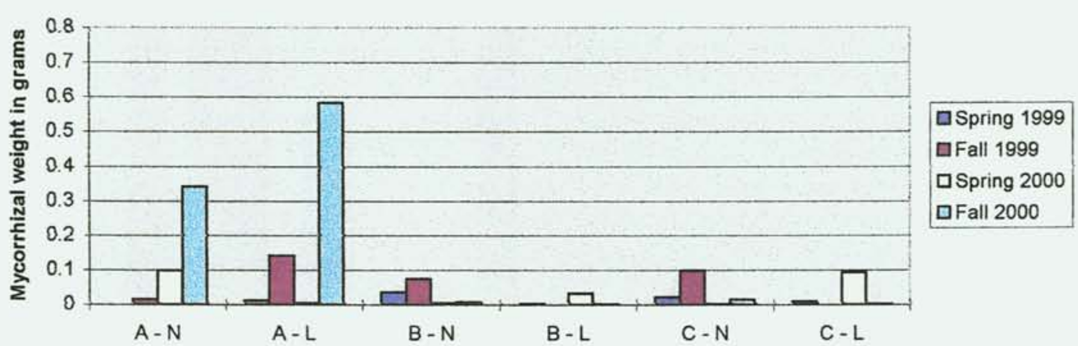
Graph B3-13: Fagirhiza fusca. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depths in an oak forest.



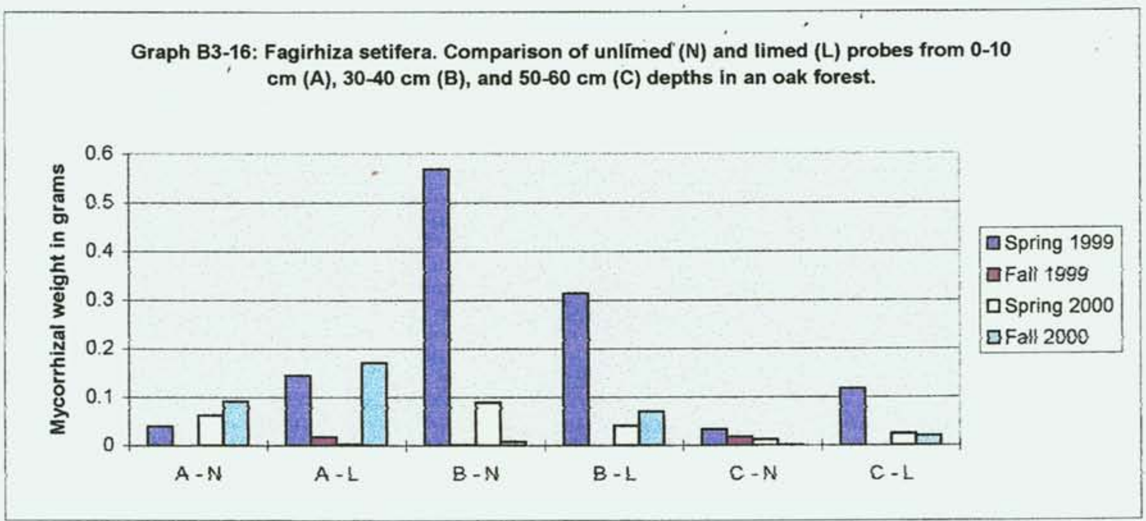
Graph B3-14: Fagirhiza globulifera. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.

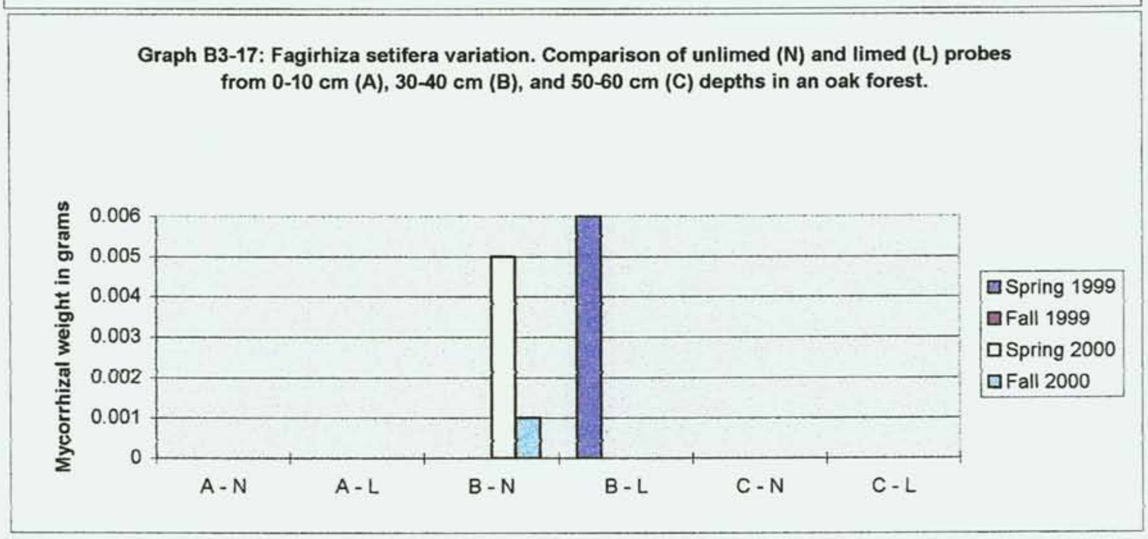


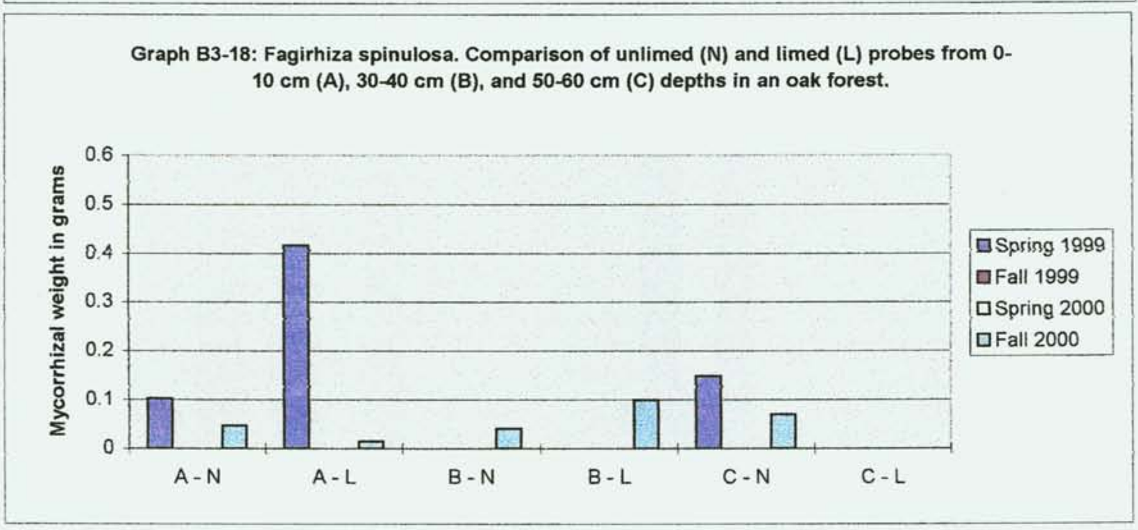
Graph B3-15: Fagirhiza granulosa. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depths in an oak forest.



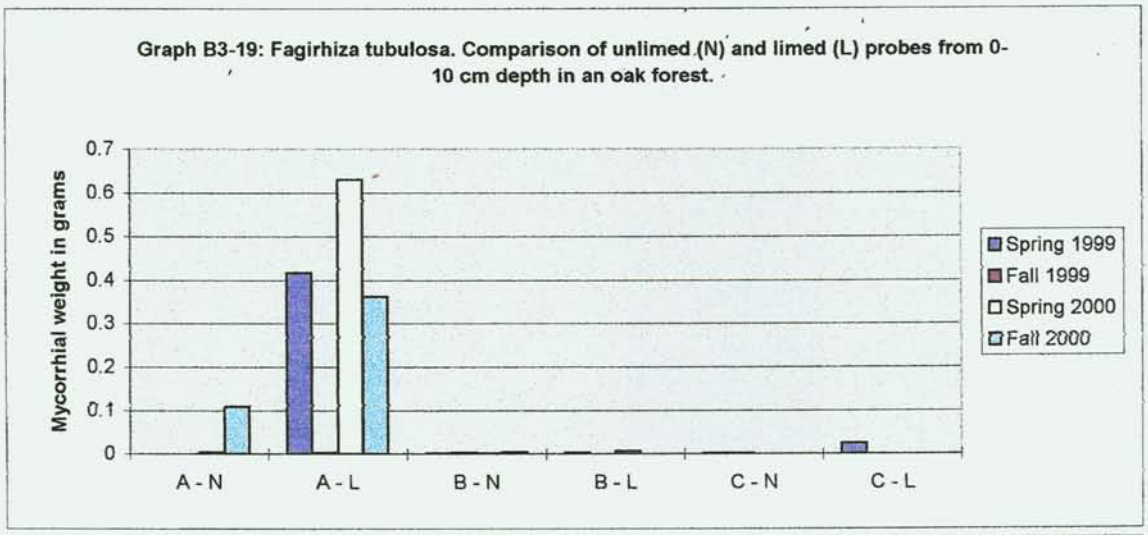
Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depth from an oak forest in Merzalben, Rheiland- Pfalz, Germany.

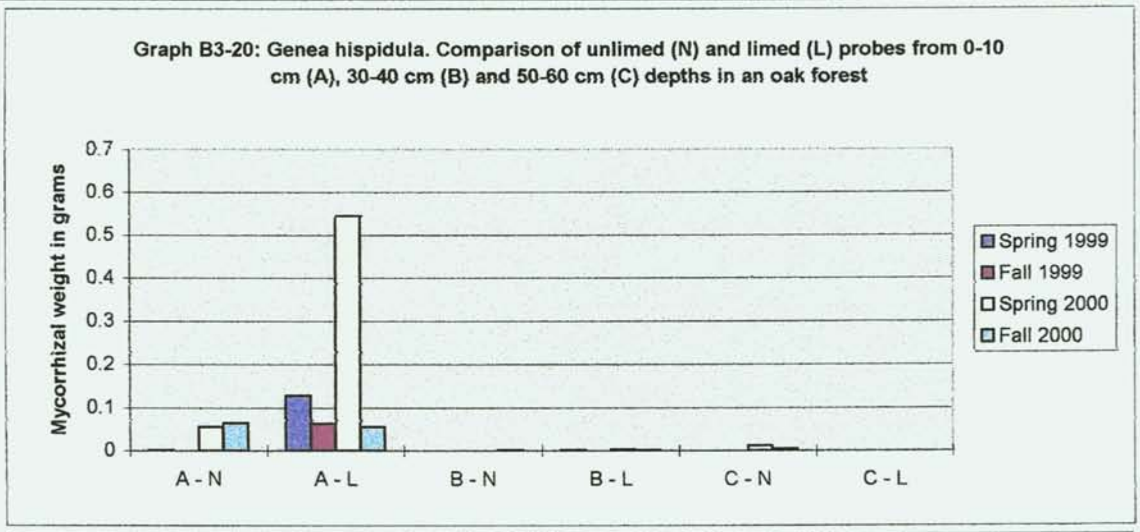


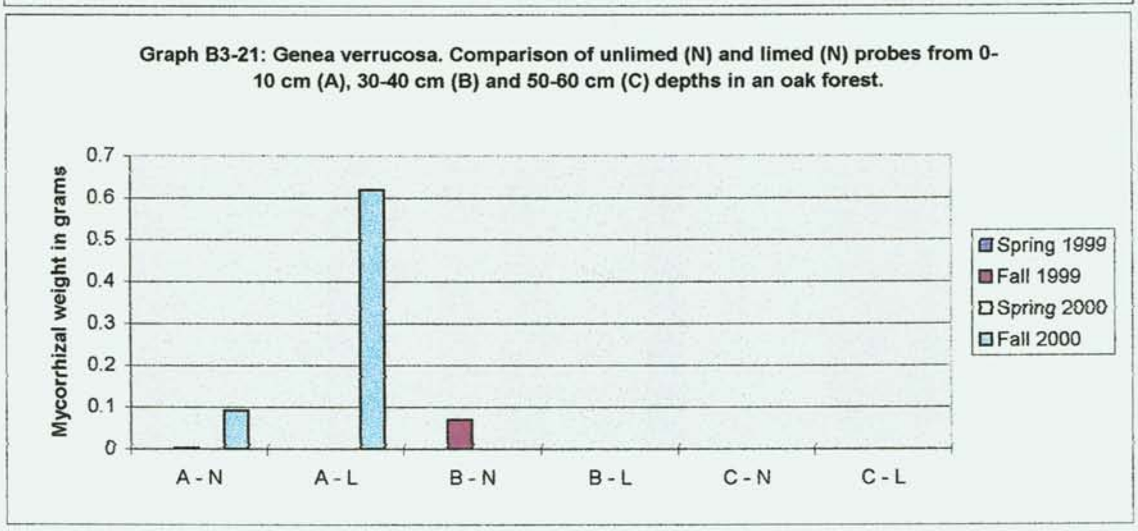




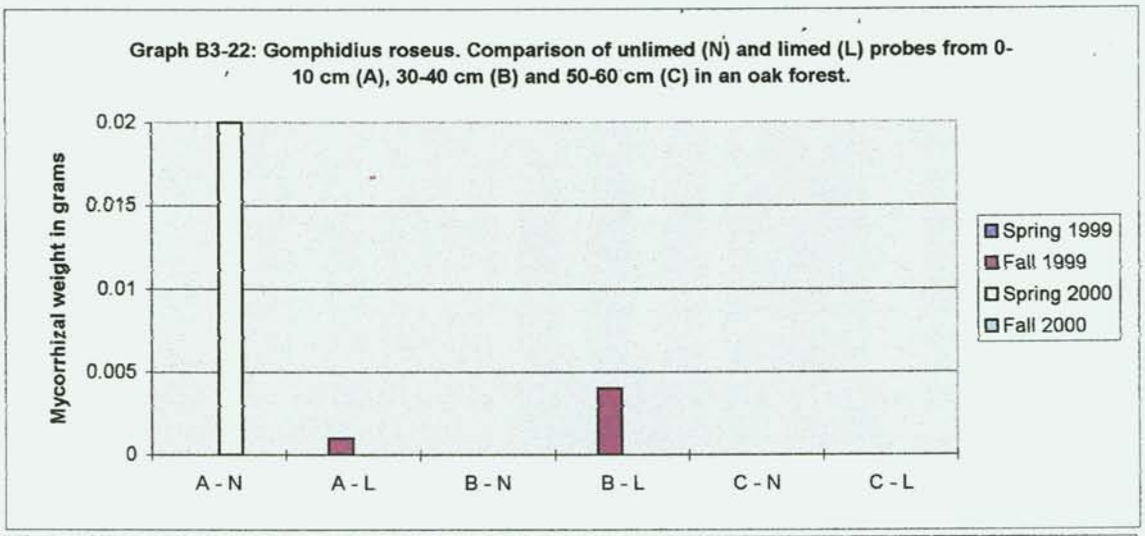
Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depth from an oak forest in Merzalben, Rheiland- Pfalz, Germany.

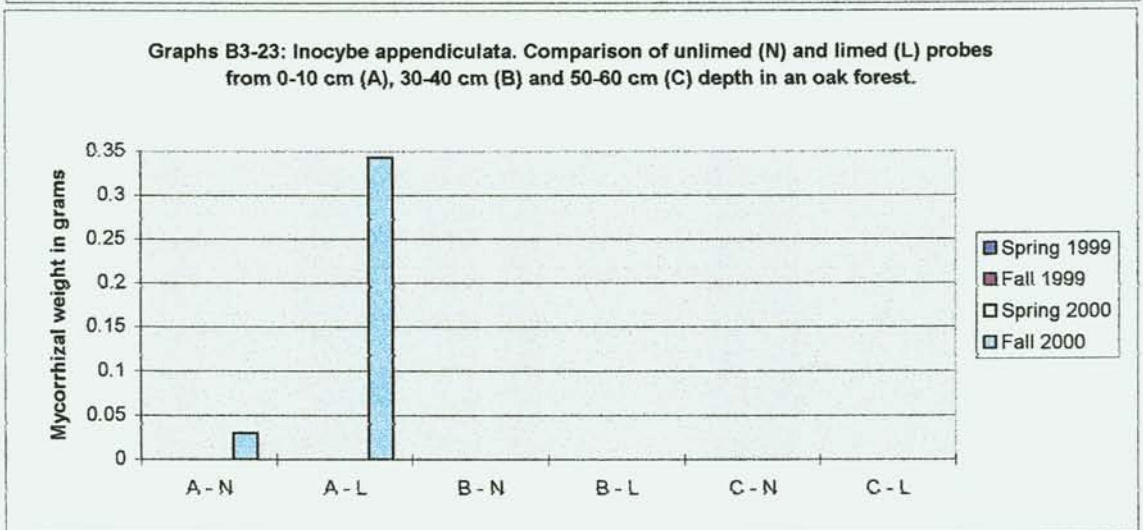


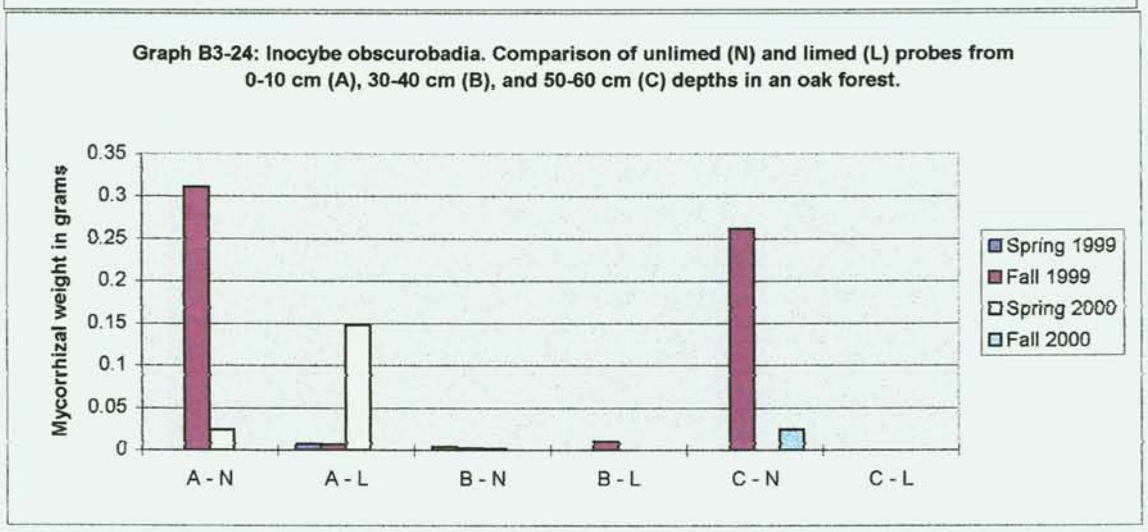




Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B), 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pflaz, Germany.

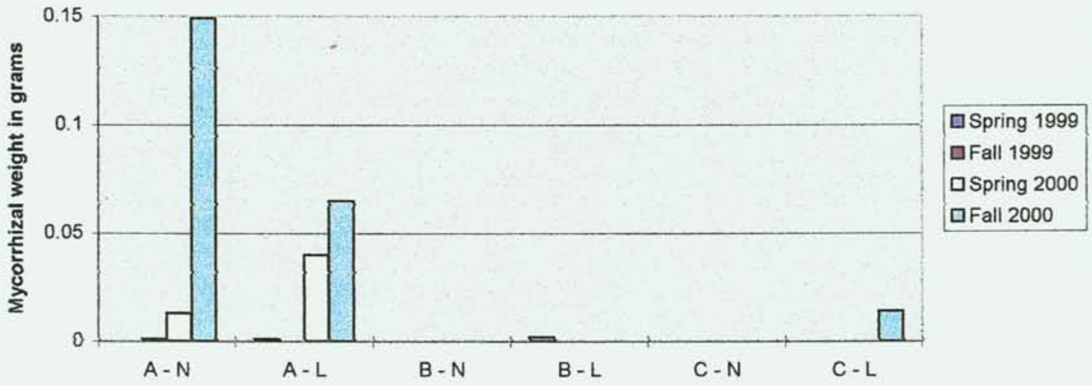




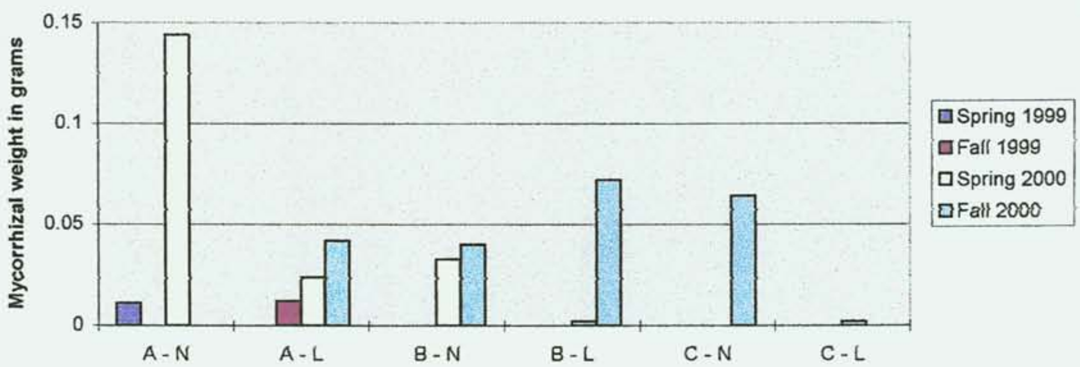


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pfalz, Germany

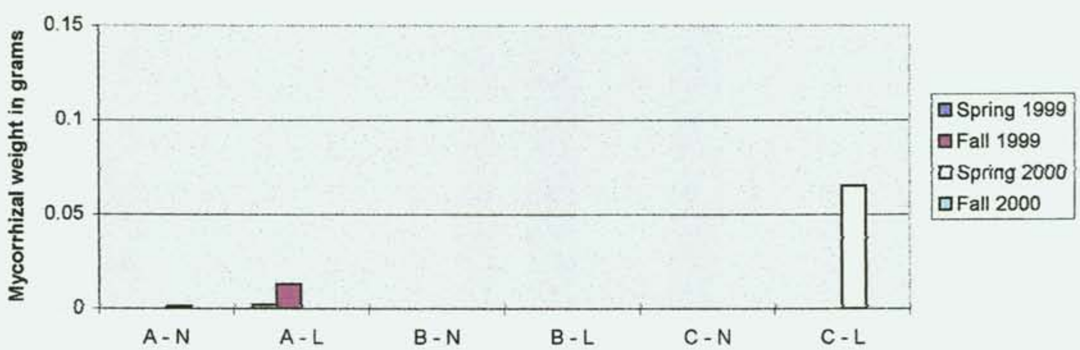
Graph B3-25: Laccaria amethystina. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.



Graph B3-26: Lactarius acris. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-6 cm (C) depths in an oak forest.

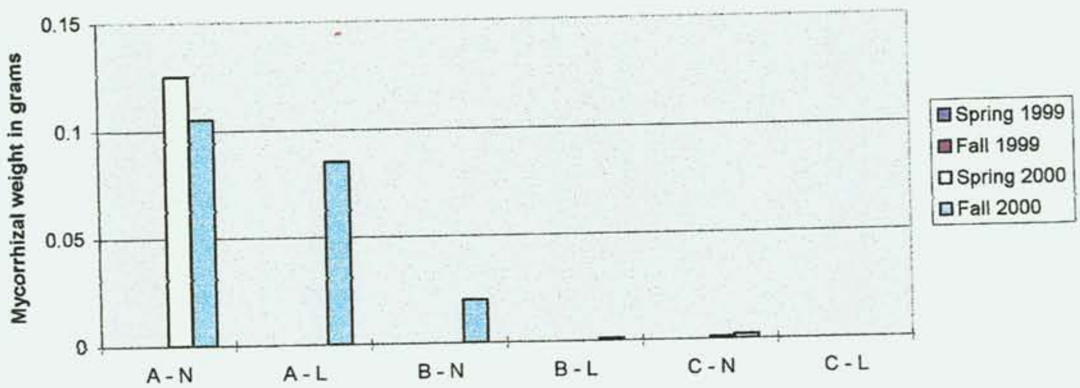


Graph B3-27: Lactarius chrysorrheus. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.

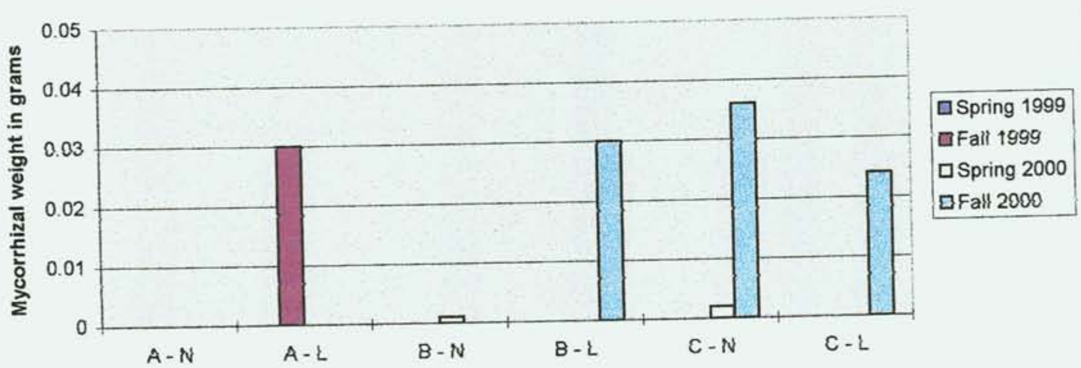


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pfalz, Germany

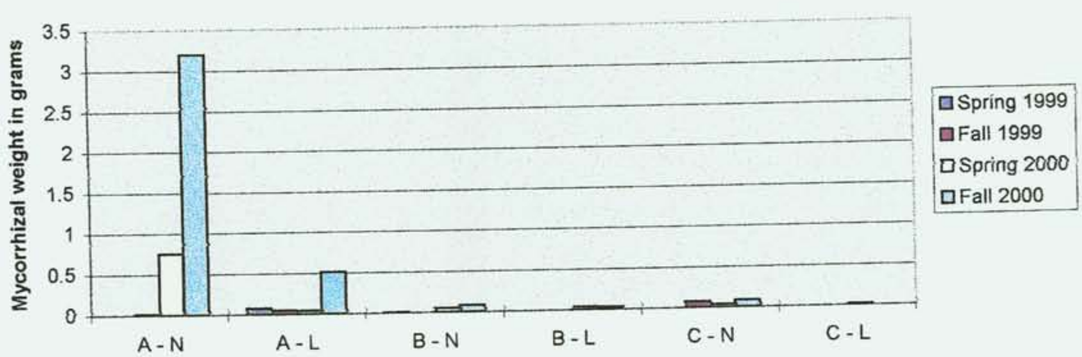
Graph B3-28: Lactarius pallidus. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.



Graph B3-29: Lactarius rubrocinctus. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depths in an oak forest.

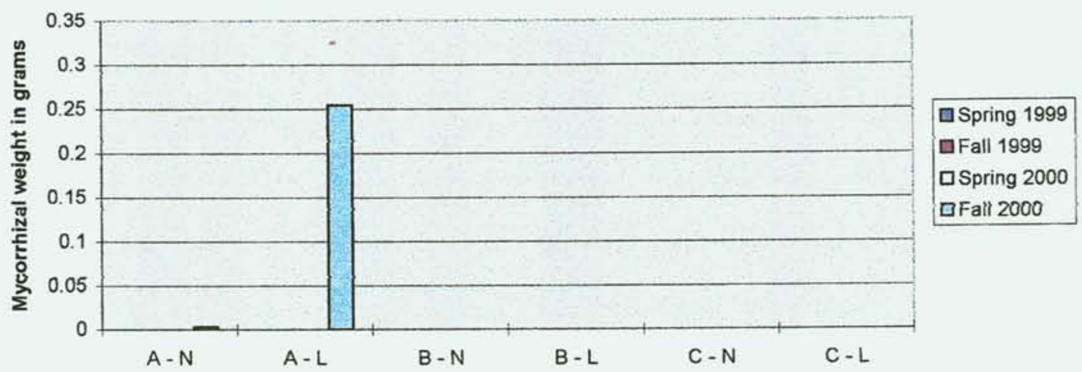


Graph B3-30: Lactarius subdulcis. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.

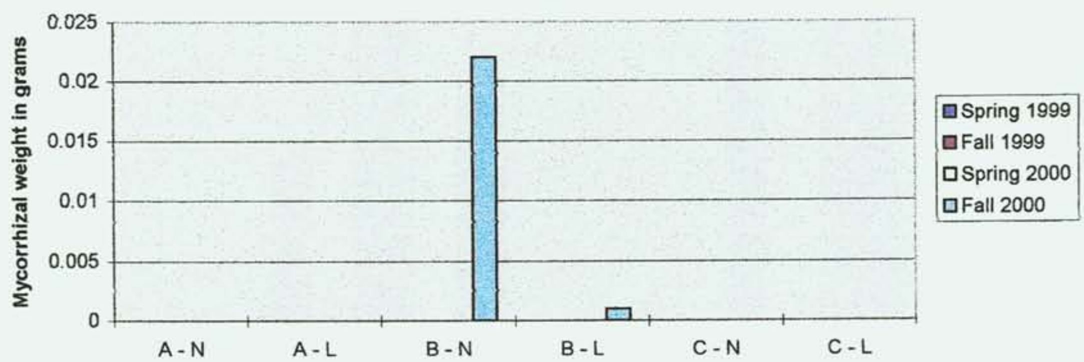


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pflaz, Germany.

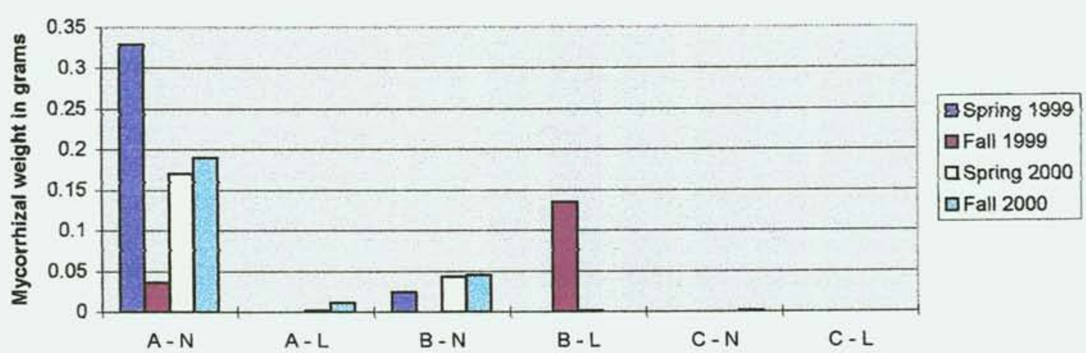
Graph B3-31: Lactarius vellereus. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-60 (C) depths in an oak forest.



Graph B3-32: Leccium scabrum. Comparison of unlimed (N) and limed (L) probes at 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.

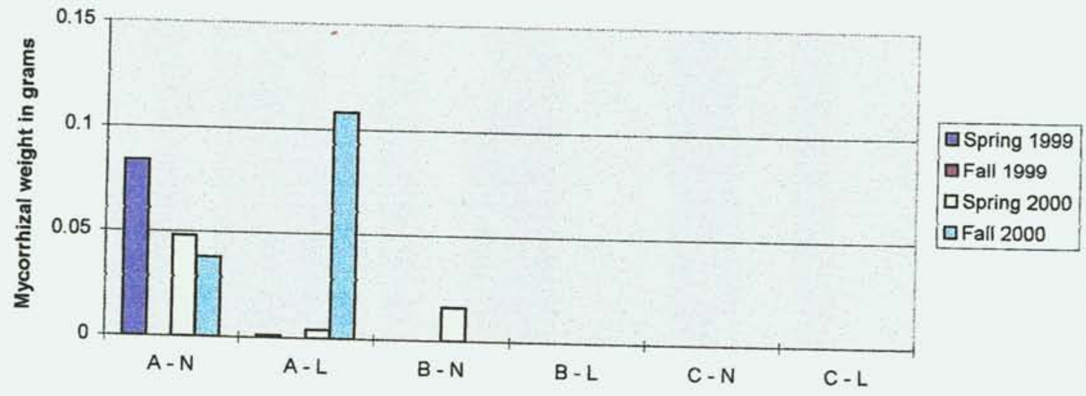


Graph B3-33: Paxillus involutus. Comparison of unlimed (N) and limed (L) probes at 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depths in an oak forest.

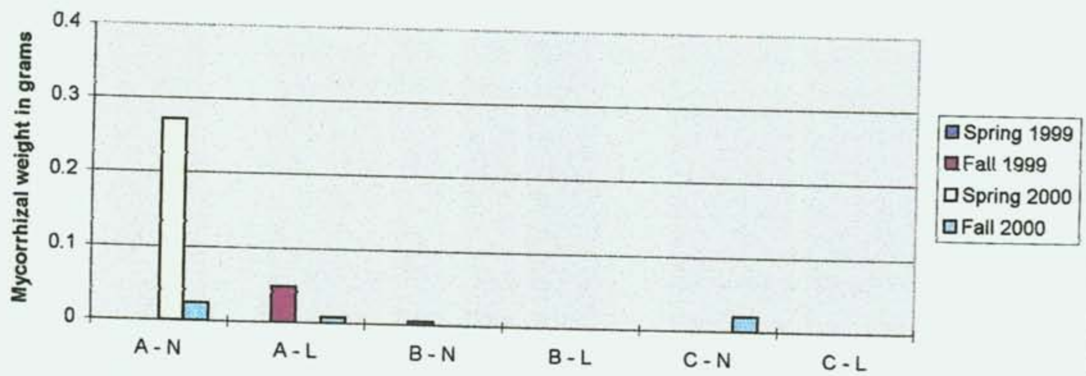


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pflaz, Germany.

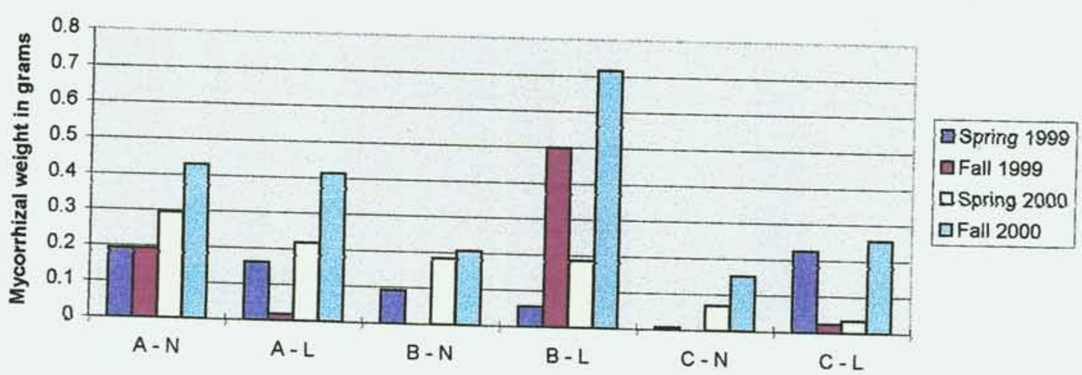
Graph B3-34: Phellodon niger. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths.



Graph B3-35: Piceirhiza bicolorata. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.

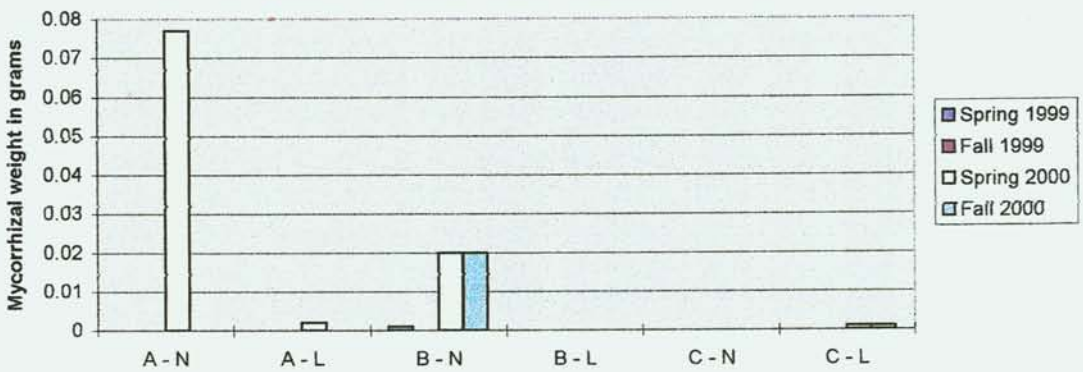


Graph B3-36: Piceirhiza chordata. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depths in an oak forest.

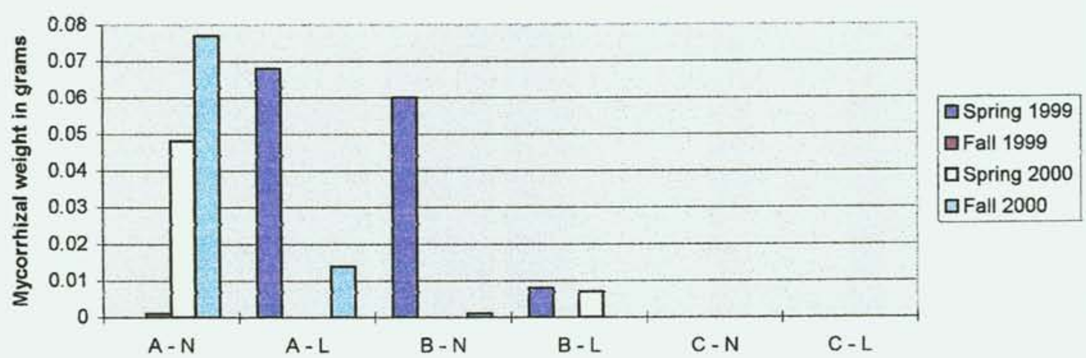


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pflaz, Germany.

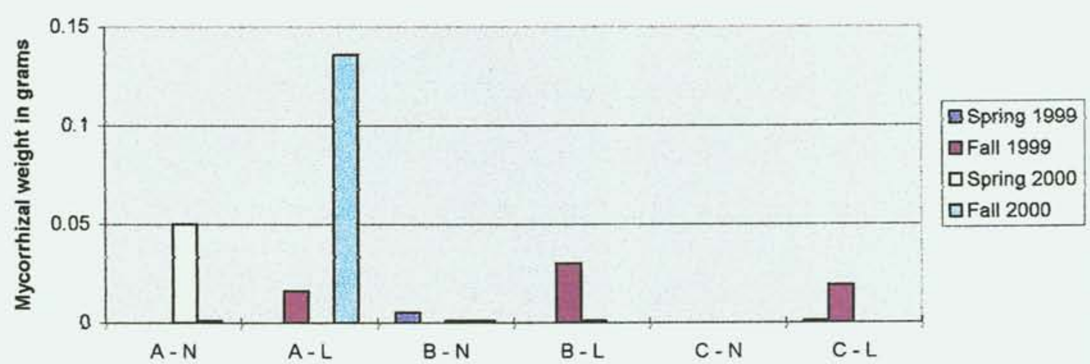
Graph B3-37: Piceirhiza gelatinosa. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.



Graph B3-38: Piceirhiza glutinosa. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.

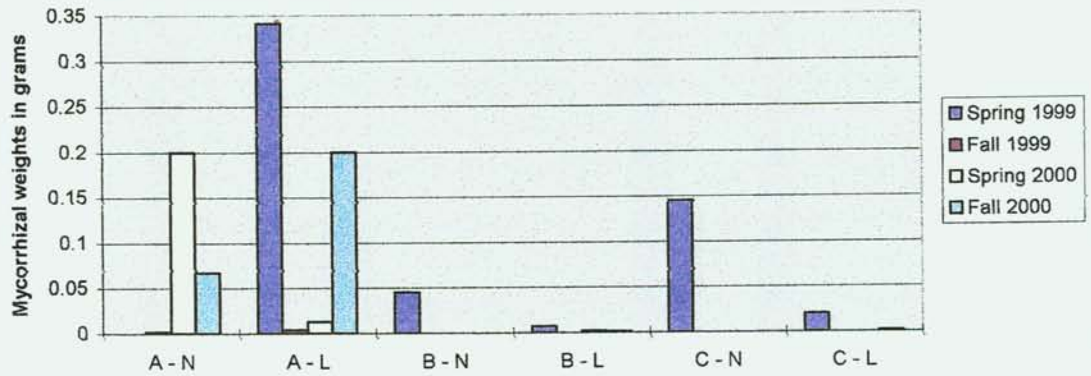


Graph B3-39: Piceirhiza guttata. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.

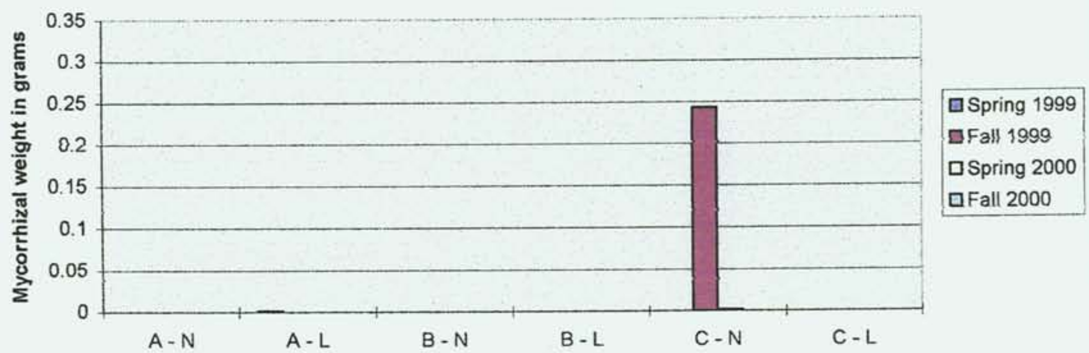


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pflaz, Germany.

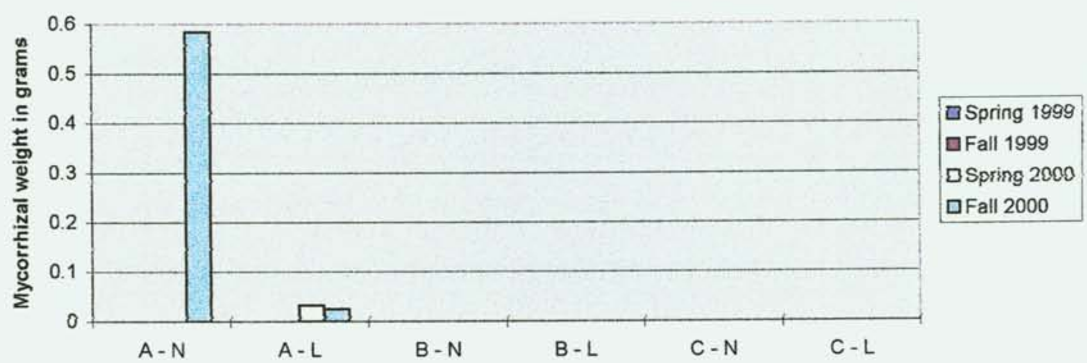
Graph B3-40: Piceirhiza nigra. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), 50-60 cm (C) depths in an oak forest.



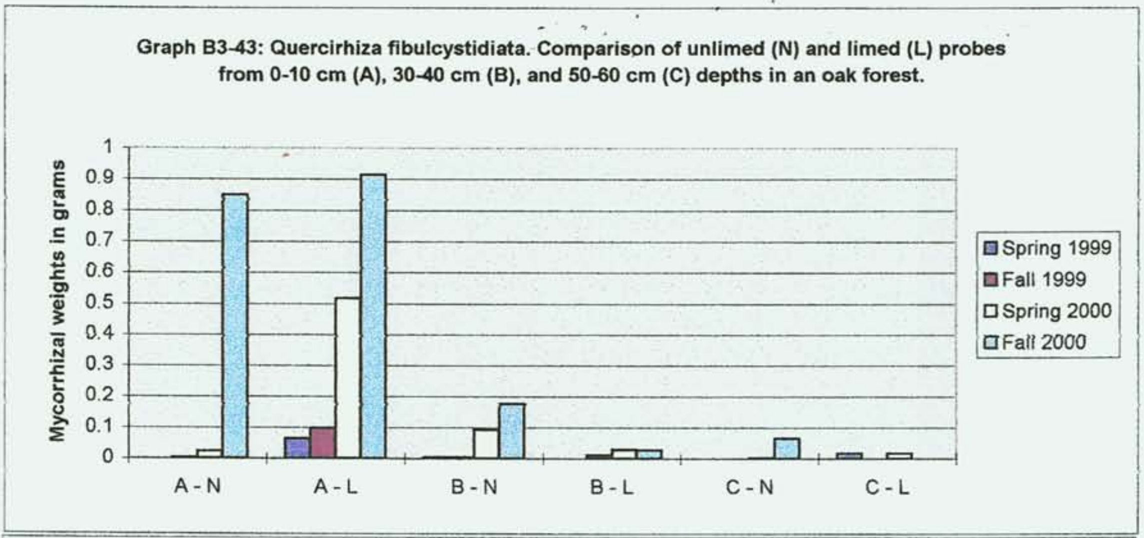
Graph B3-41: Pinirhiza rufomaculata. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depths in an oak forest.

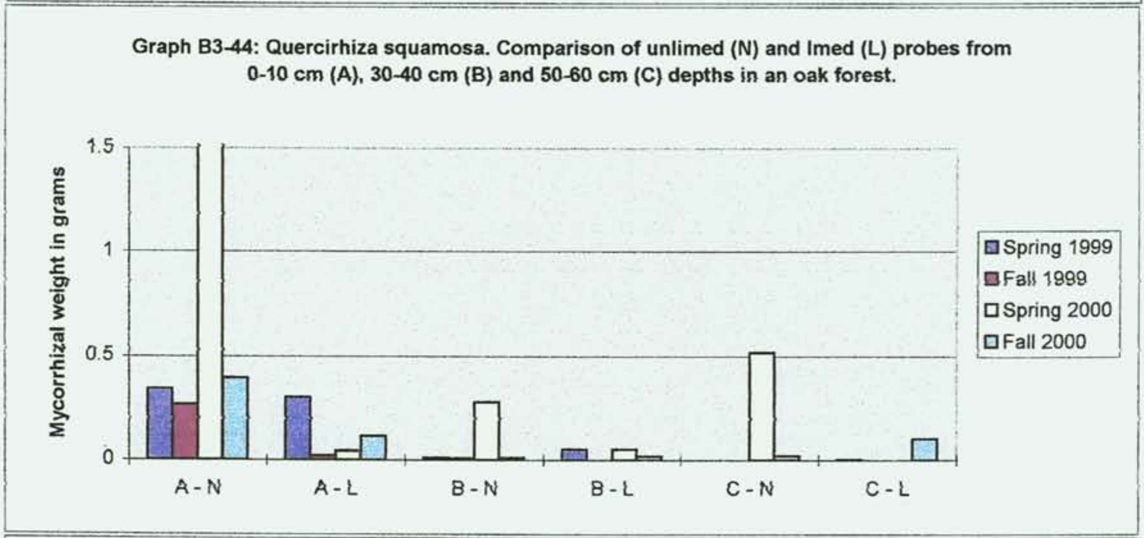


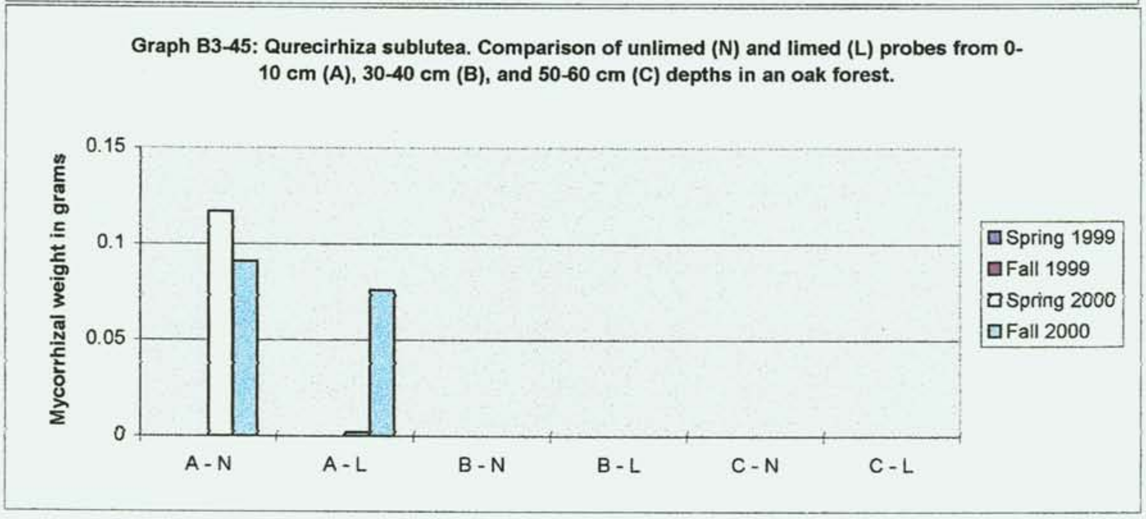
Graph B3-42: Pseudotomentella tristis. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depths in an oak forest.



Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pflaz, Germany.

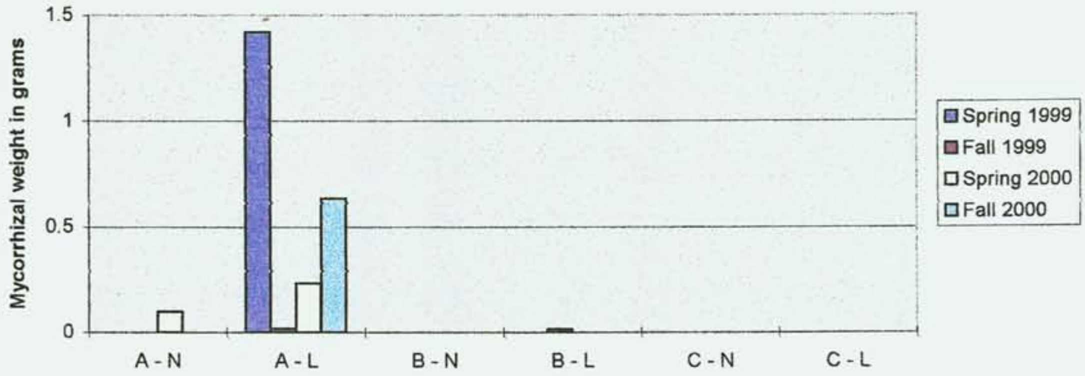




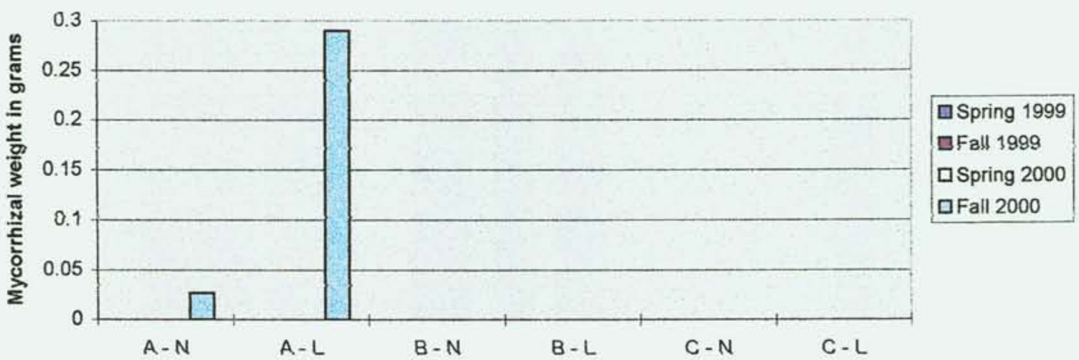


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pflaz, Germany

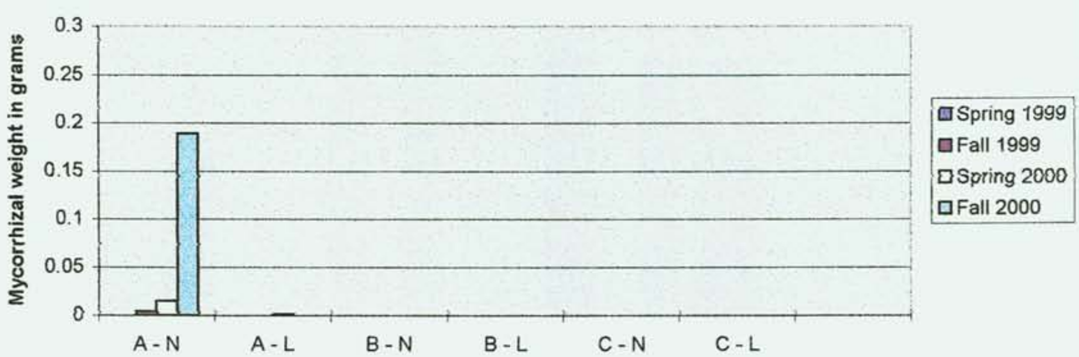
Graph B3-46: Russula acrifolia. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depths in an oak forest.



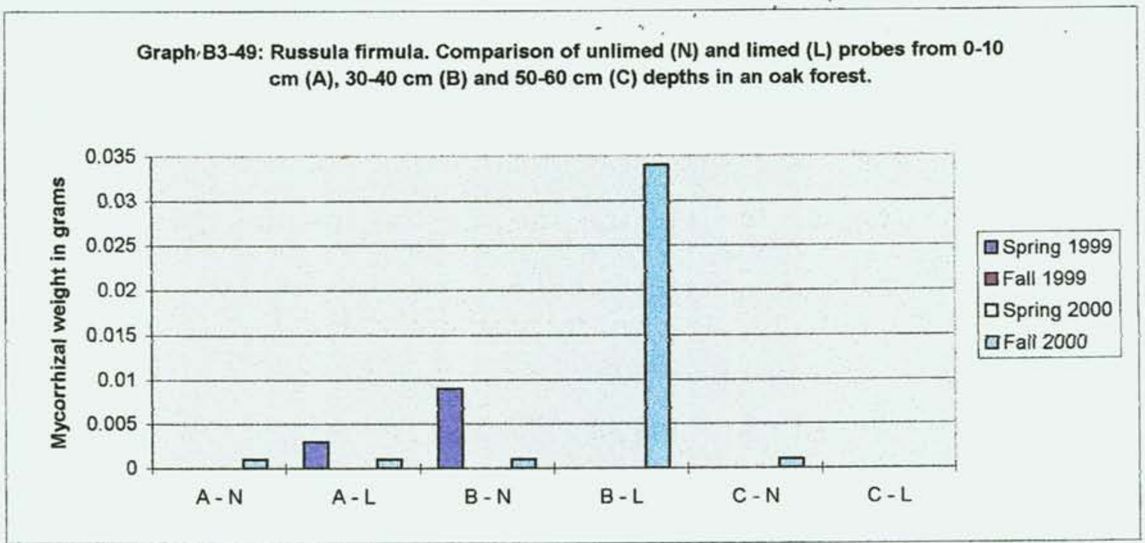
Graph B3-47: Russula acris. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depth in an oak forest.

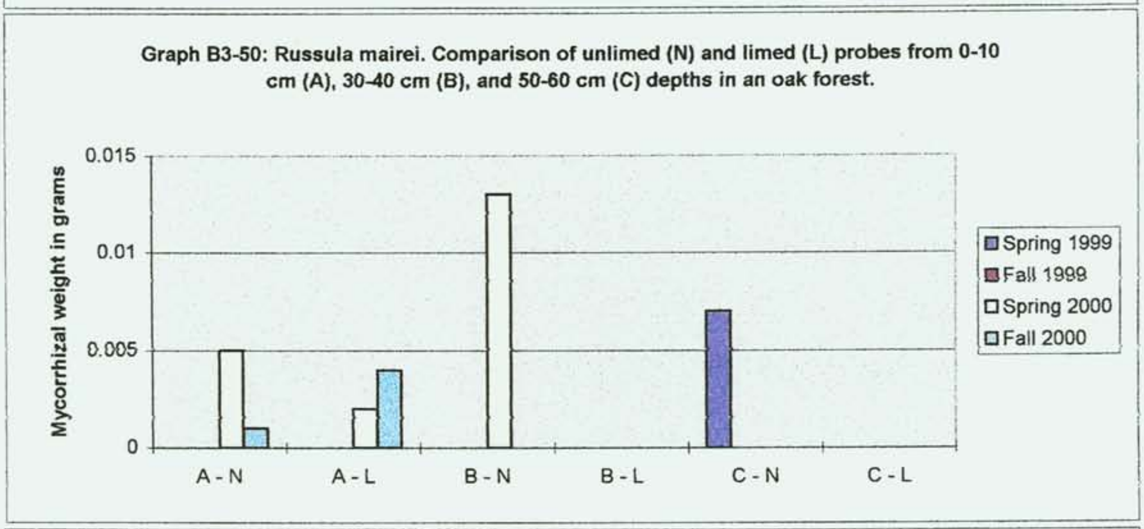


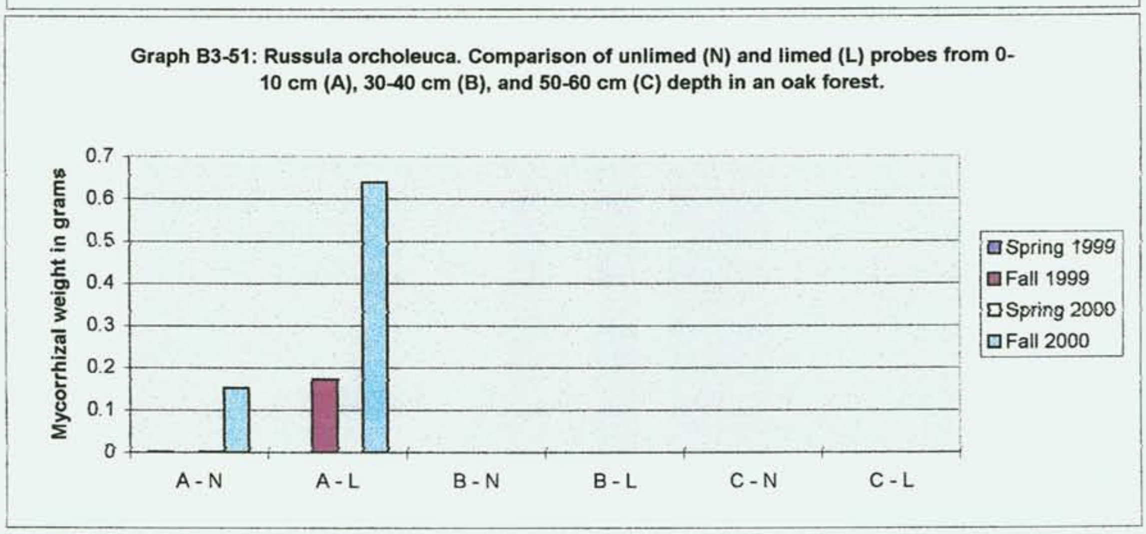
Graph B3-48: Russula feuginea. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth in an oak forest.



Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B), and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pflaz, Germany

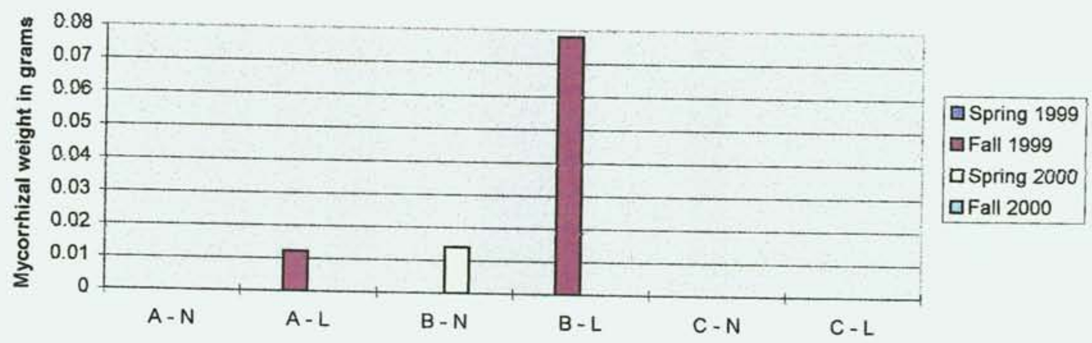




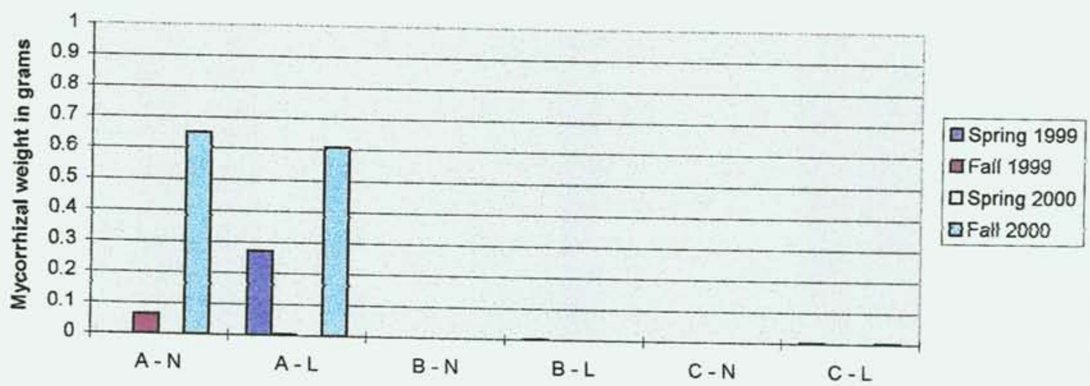


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pfalz, Germany.

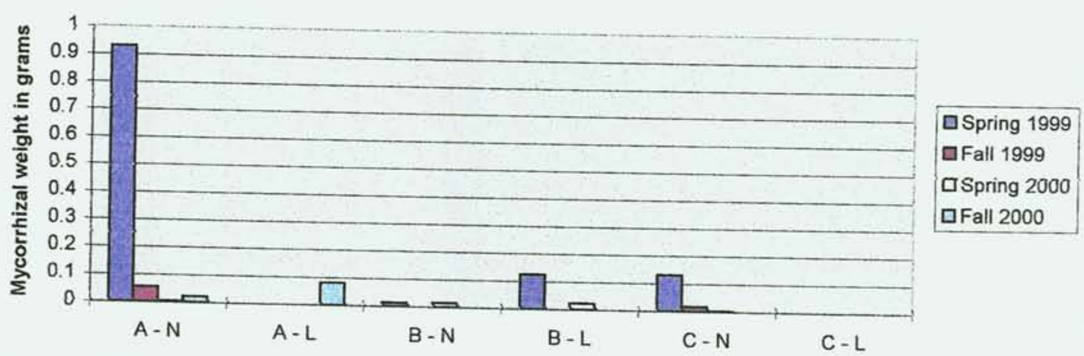
Graph B3-52: Tetraberlineaerhiza bicolor. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.



Graph B3-53: Tomentella ferruginea. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.

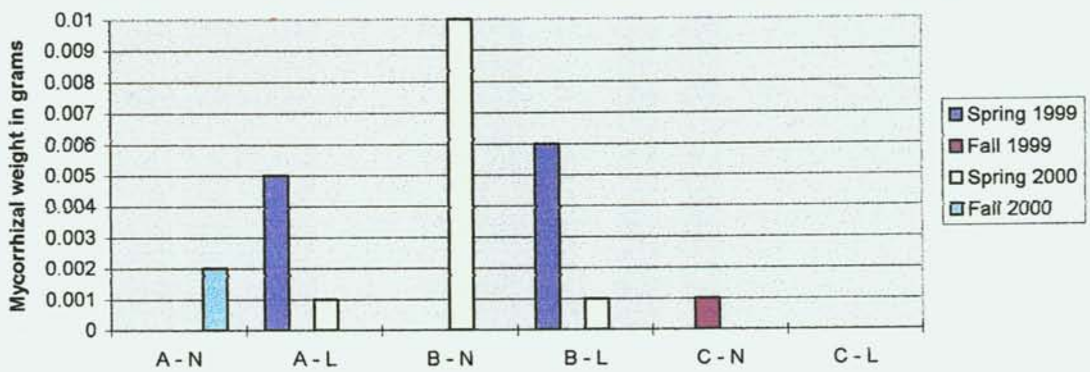


Graph B3-54: Tuber melanosporum. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths in an oak forest.

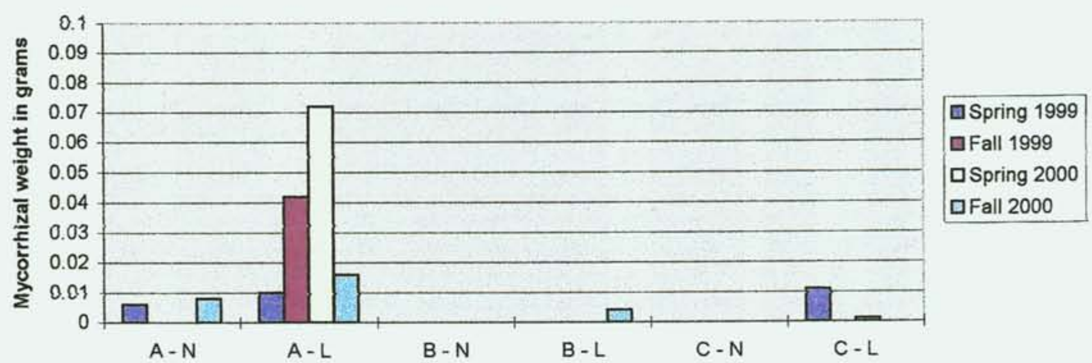


Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pflaz, Germany

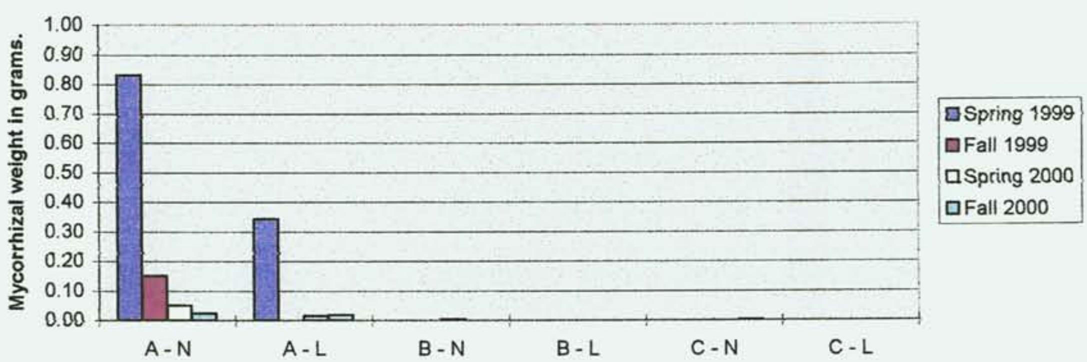
Graph B3-55: Tuber mesentericum. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth in an oak forest.



Graph B3-56: Tuber puberulum. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth in an oak forest.

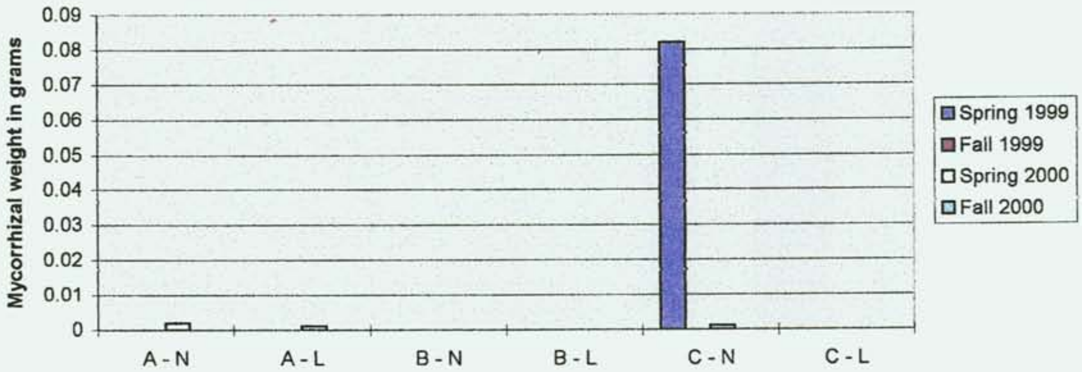


Graph B3-57: Tuber rufum. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth in an oak forest.

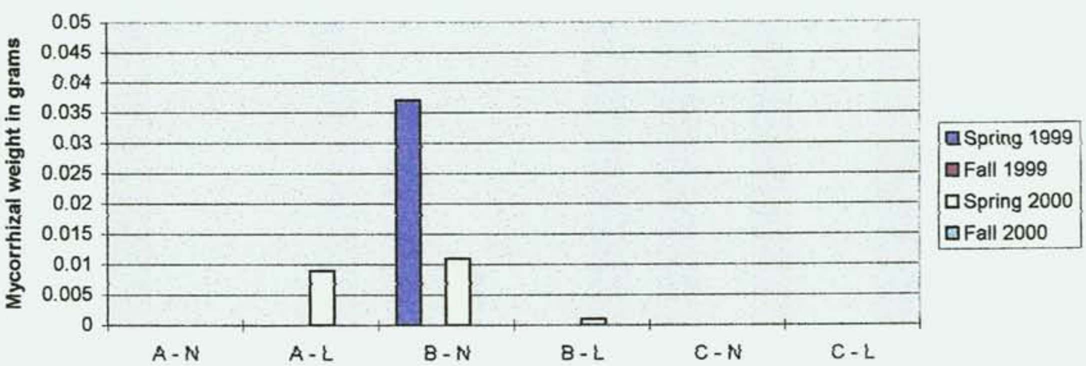


Appendix 8A: Myocorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pfalz, Germany.

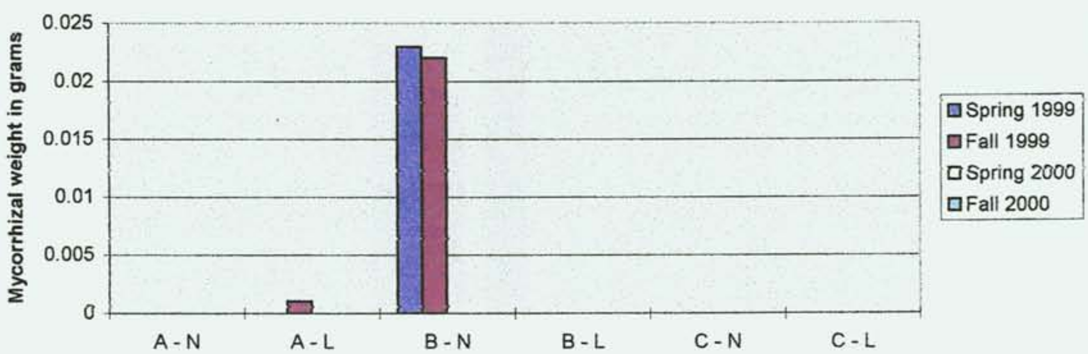
Graph B3-58: Tuber unknown A. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth in an oak forest.



Graph B3-59: Tuber unknown B. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth in an oak forest.

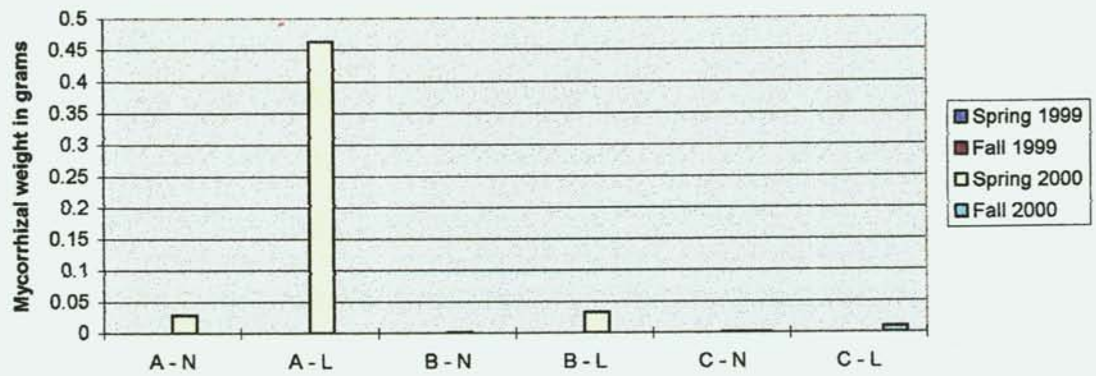


Graph B3-60: Tuber unknown D. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth in an oak forest.

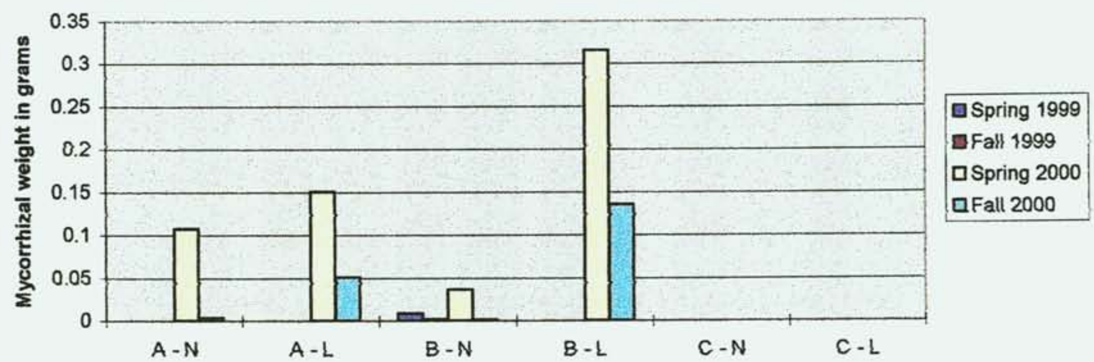


Appendix 8A: Myocorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Rheinland-Pfalz, Germany.

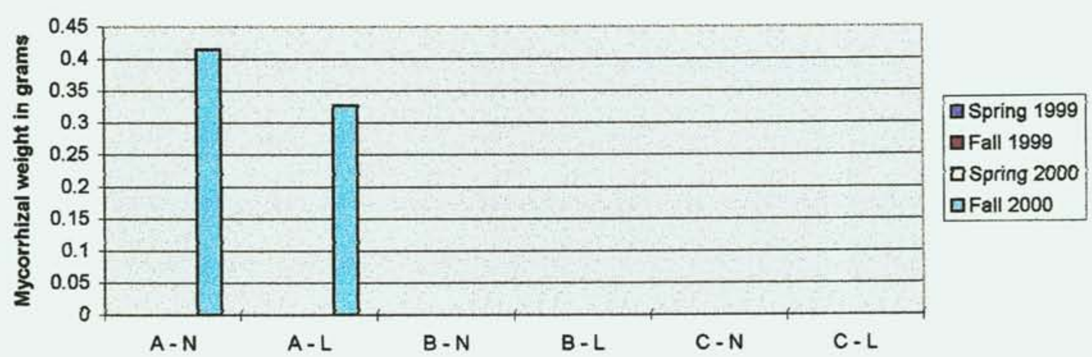
Graph B3-61: Unknown - Bicolorata. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth in an oak forest.



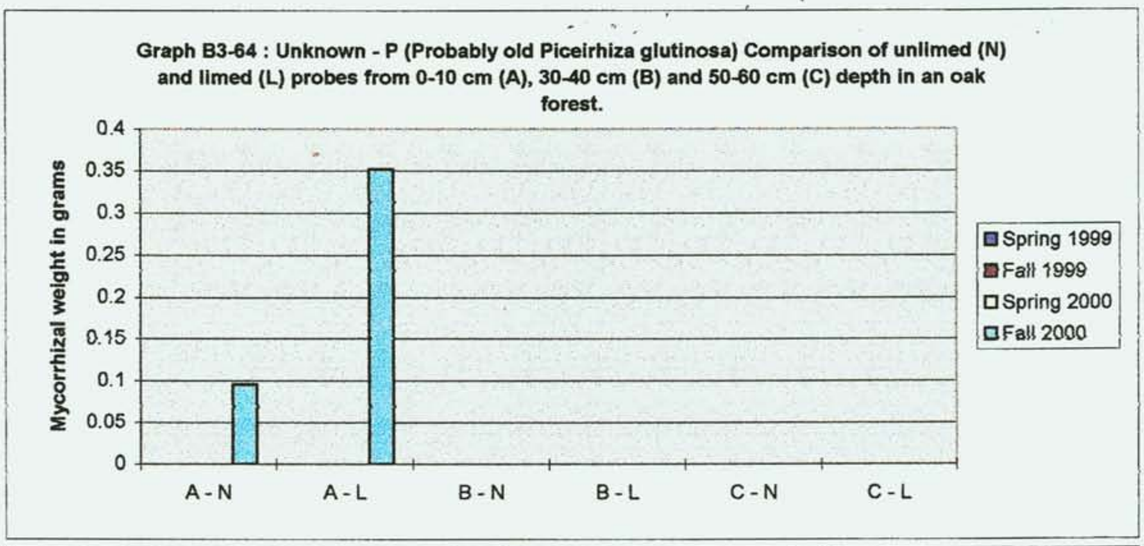
Graph B3-62: Unknown - Br & clear. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm depth in an oak forest.

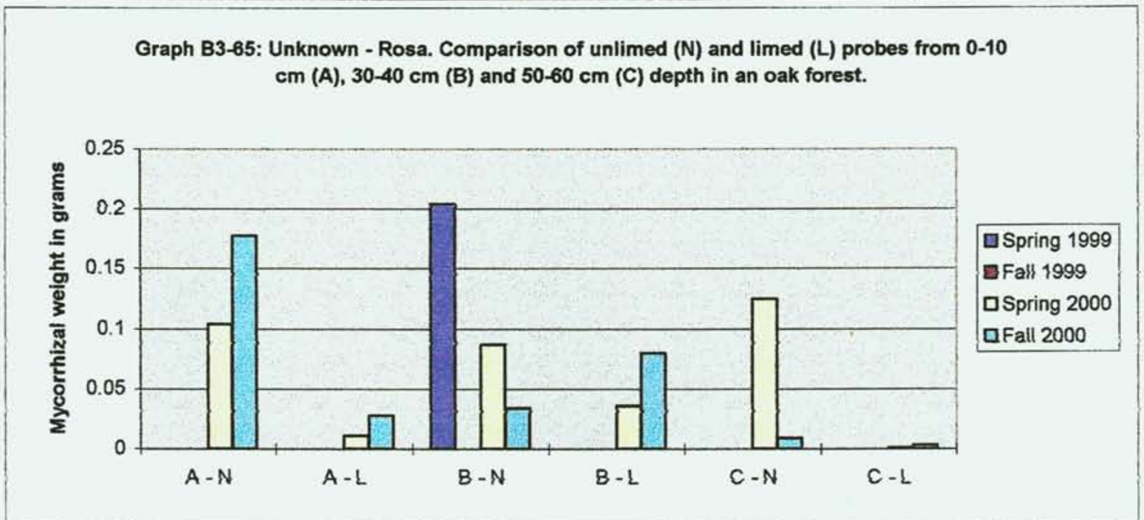


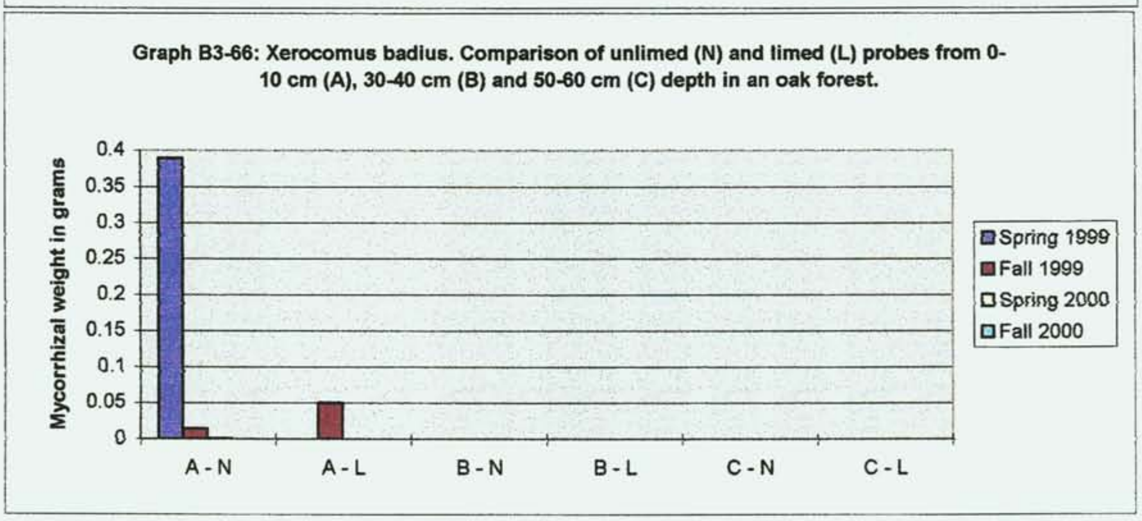
Graph B3-63: Unknown - Gray. Comparison of unlimed (N) and limed (L) probes from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth in an oak forest.



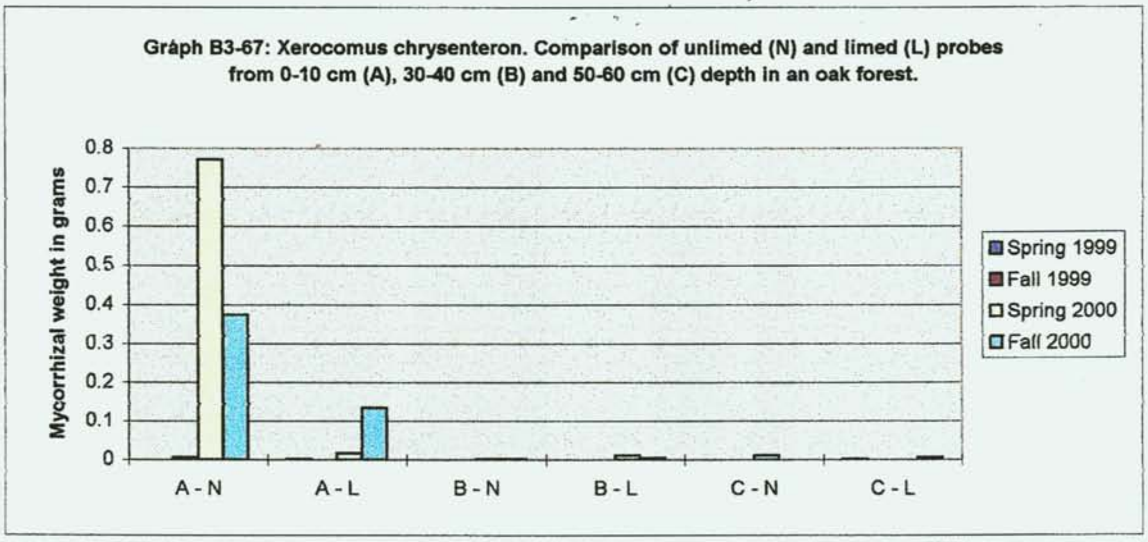
Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Reinland-Pfalz, Germany.

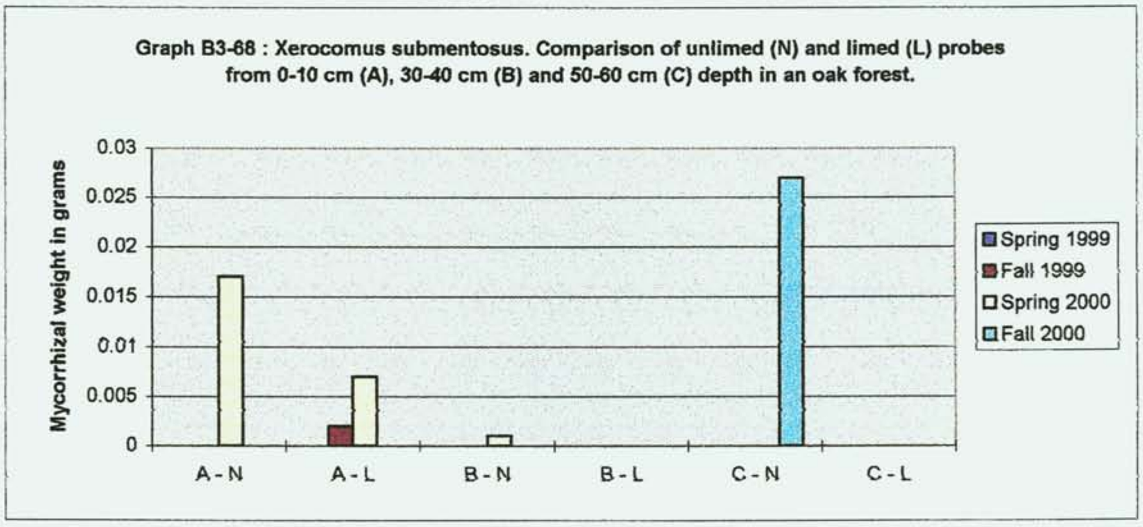






Appendix 8A: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depths from an oak forest in Merzalben, Reinland-Pfalz, Germany.





Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Amphinema byssoides

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.006	0.030	0.023	0.059
A - L	0.001	0.138	0.102	0.248	0.489
B - N			0.039		0.039
B - L			0.028	0.026	0.054
C - N	0.001			0.012	0.013
C - L				0.001	0.001

Boletus cavipes

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N		0.014	0.014		0.028
B - L					
C - N					
C - L					

Boletus edulis

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.003	0.700	0.703
A - L		0.002	0.016	0.084	0.102
B - N	0.010	0.031	0.546	0.001	0.588
B - L			0.002	0.001	0.003
C - N		0.002	0.215	0.009	0.226
C - L			0.001		0.001

Byssocorticium atrovirens

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.187	0.043	0.230
A - L			0.002	0.072	0.074
B - N	0.001		0.003	0.058	0.062
B - L		0.002	0.031	0.013	0.046
C - N			0.001	0.008	0.009
C - L	0.002		0.002	0.016	0.020

Cenococcum geophilum

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	1.336	0.160	2.735	1.599	5.830
A - L	0.143	0.299	1.922	1.536	3.900
B - N	0.157	0.829	0.672	0.339	1.997
B - L	0.236	0.035	0.864	1.118	2.253
C - N	0.002	0.009	0.151	0.201	0.363
C - L	0.060	0.001	0.043	0.118	0.222

Cenococcum geophilum variation

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.054	0.002	0.002		0.058
A - L	0.046				0.046
B - N	0.001	0.001			0.002
B - L				0.001	0.001
C - N				0.007	0.007
C - L				0.091	0.091

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Cenococcum geophilum
Sporeballs only

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.092	0.368	0.460
A - L			0.010	0.435	0.445
B - N			0.050	0.009	0.059
B - L			0.002	0.010	0.012
C - N			0.003	0.003	0.006
C - L			0.004	0.010	0.014

Cortinarius armillatus

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.008	0.167	0.175
A - L		0.286	0.029	0.904	1.219
B - N	0.001		0.112	0.001	0.114
B - L	0.001	0.014	0.065		0.080
C - N		0.004	0.015	0.004	0.023
C - L			0.043	0.001	0.044

Cortinarius bolaris

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L	0.003	0.153	0.075		0.231
B - N	0.040		0.020		0.060
B - L	0.010			0.010	0.020
C - N	0.005	0.018	0.018	0.002	0.043
C - L					0.000

Cortinarius varicolor

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N		0.004			0.004
B - L					
C - N					
C - L					

Dermocybe cinnamomea

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L	0.011				0.011
B - N					
B - L	0.009				0.009
C - N					
C - L					

Dermocybe species

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L	0.001				0.001
B - N					
B - L					
C - N					
C - L					

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Elaphomyces muricatus

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.007	0.007
A - L				0.046	0.046
B - N	0.130				0.130
B - L	0.040		0.225	0.211	0.476
C - N	0.002				0.002
C - L	0.030		0.235	0.394	0.659

Entoloma sinuatum

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L			0.013		0.013
B - N					
B - L					
C - N					
C - L					

Fagirhiza arachnoidea

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.001			0.054	0.055
A - L		0.007	0.038	0.077	0.122
B - N					
B - L			0.019		0.019
C - N					
C - L				0.010	0.010

Fagirhiza cystidiophora

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.002	0.319	0.321
A - L	0.135			0.007	0.142
B - N					
B - L					
C - N					
C - L					

Fagirhiza fusca

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.043	0.026	0.069
A - L	0.022	0.038	0.732	0.581	1.373
B - N	0.048		0.212		0.260
B - L	0.015		0.014	0.009	0.038
C - N			0.011	0.003	0.014
C - L	0.552				0.552

Fagirhiza globulifera

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L		0.002		0.001	0.003
B - N					
B - L					
C - N		0.017			0.017
C - L					

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Fagirhiza granulosa

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.016	0.099	0.341	0.456
A - L	0.012	0.142	0.004	0.583	0.741
B - N	0.035	0.075	0.004	0.007	0.121
B - L	0.003		0.033	0.001	0.037
C - N	0.021	0.098	0.001	0.016	0.136
C - L	0.009		0.094	0.002	0.105

Fagirhiza setifera

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.039		0.062	0.091	0.192
A - L	0.144	0.017	0.002	0.171	0.334
B - N	0.568	0.001	0.088	0.008	0.665
B - L	0.314		0.040	0.070	0.424
C - N	0.033	0.017	0.012	0.001	0.063
C - L	0.117		0.024	0.020	0.161

Fagirhiza setifera variation

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N			0.005	0.001	0.006
B - L	0.006				0.006
C - N					
C - L					

Fagirhiza species unknown

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.010		0.010
A - L			0.001		0.001
B - N					
B - L					
C - N					
C - L					

Fagirhiza spinulosa

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.102			0.047	0.149
A - L	0.416			0.014	0.43
B - N				0.040	0.04
B - L				0.099	0.099
C - N	0.148			0.070	0.218
C - L					

Fagirhiza tubulosa
(Sphaerozona astiolatum)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.004	0.109	0.113
A - L	0.416	0.003	0.630	0.362	1.411
B - N	0.001	0.003	0.001	0.004	0.009
B - L	0.003		0.006		0.009
C - N	0.001	0.001			0.002
C - L	0.025				0.025

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Genea hispidula

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.001		0.056	0.064	0.120
A - L	0.128	0.063	0.544	0.055	0.599
B - N				0.001	0.001
B - L	0.001		0.003	0.001	0.004
C - N			0.011	0.004	0.015
C - L					

Genea verrucosa

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.003		0.092	0.095
A - L				0.619	0.619
B - N		0.070			0.070
B - L					
C - N					
C - L					

Gomphidius roseus

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.020		0.020
A - L		0.001			0.001
B - N					
B - L		0.004			0.004
C - N					
C - L					

Hydnum rufescens

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N					
B - L	0.002				0.002
C - N					
C - L					

Inocybe appendiculata

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.030	0.030
A - L				0.343	0.343
B - N					
B - L					
C - N					
C - L					

Inocybe obscurobadia

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.311	0.024		0.335
A - L	0.007	0.006	0.148		0.161
B - N	0.004	0.002	0.001		0.007
B - L		0.010			0.010
C - N		0.262		0.024	0.286
C - L					

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Laccaria amethystina
(Laccaria amethystea)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.001	0.013	0.149	0.163
A - L	0.001		0.040	0.065	0.106
B - N					
B - L	0.002				0.002
C - N					
C - L				0.014	0.014

Laccaria species unknown

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N			0.001		0.001
B - L	0.024				0.024
C - N					
C - L					

Lactarius acris

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.011		0.144		0.155
A - L		0.012	0.024	0.042	0.078
B - N			0.033	0.040	0.073
B - L			0.002	0.072	0.074
C - N				0.064	0.064
C - L			0.002		0.002

Lactarius chrysorrheus

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.001		0.001
A - L	0.002	0.013			0.015
B - N					
B - L					
C - N					
C - L			0.065		0.065

Lactarius pallidus

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.125	0.105	0.23
A - L				0.085	0.085
B - N				0.020	0.020
B - L				0.001	0.001
C - N			0.001	0.002	0.003
C - L					

Lactarius picinus

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N					
B - L	0.001				0.001
C - N					
C - L					

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Lactarius porninsis

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.003	0.003
A - L					
B - N					
B - L					
C - N					
C - L					

Lactarius rubrocinctus

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L		0.030			0.030
B - N			0.001		0.001
B - L				0.030	0.03
C - N			0.002	0.036	0.038
C - L				0.024	0.024

Lactarius species unknown

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L			0.054		0.054
B - N					
B - L			0.007		0.007
C - N					
C - L	0.001				0.001

Lactarius subdulcis

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.011	0.755	3.202	3.968
A - L	0.074	0.043	0.042	0.512	0.671
B - N	0.006	0.002	0.044	0.08	0.132
B - L		0.001	0.032	0.026	0.059
C - N	0.003	0.074	0.03	0.088	0.195
C - L	0.001	0.001	0.014	0.002	0.018

Lactarius vellereus

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.003	0.003
A - L				0.254	0.254
B - N					
B - L					
C - N					
C - L					

Leccium scabrum

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N				0.022	0.022
B - L				0.001	0.001
C - N					
C - L					

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Leucangium carthusianum

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N					
B - L					
C - N					
C - L	0.023				0.023

Paxillus involutus

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.329	0.036	0.17	0.19	0.725
A - L			0.002	0.011	0.013
B - N	0.024		0.043	0.045	0.112
B - L		0.135	0.001		0.136
C - N				0.001	0.001
C - L					

Phellodon niger

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.084		0.048	0.038	0.17
A - L	0.001		0.004	0.108	0.113
B - N			0.016		0.016
B - L					
C - N					
C - L					

Piceirhiza bicolorata

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.271	0.024	0.295
A - L		0.048		0.008	0.056
B - N		0.005			0.005
B - L					
C - N				0.021	0.021
C - L					

Piceirhiza chordata

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.192	0.192	0.294	0.429	1.107
A - L	0.161	0.018	0.217	0.413	0.809
B - N	0.092		0.184	0.205	0.481
B - L	0.056	0.499	0.186	0.716	1.457
C - N	0.008		0.07	0.153	0.231
C - L	0.225	0.023	0.034	0.256	0.538

Piceirhiza gelatinosa

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.077		0.077
A - L			0.002		0.002
B - N	0.001		0.020	0.020	0.041
B - L					
C - N					
C - L			0.001	0.001	0.002

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Piceirhiza glutinosa

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.001	0.048	0.077	0.126
A - L	0.068			0.014	0.082
B - N	0.060			0.001	0.061
B - L	0.008		0.007		0.015
C - N					
C - L					

Piceirhiza guttata

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.050	0.001	0.051
A - L		0.016		0.136	0.152
B - N	0.005		0.001	0.001	0.007
B - L		0.030	0.001		0.031
C - N					
C - L	0.001	0.019			0.020

Piceirhiza nigra

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.002	0.200	0.067	0.269
A - L	0.341	0.004	0.013	0.200	0.558
B - N	0.045				0.045
B - L	0.007		0.002	0.001	0.010
C - N	0.145				0.145
C - L	0.020			0.001	0.021

Piloderm croceum

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N					
B - L				0.002	0.002
C - N					
C - L					

Pinirhiza cyaneoviridis

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N					
B - L					
C - N	0.001	0.043			0.044
C - L					

Pinirhiza rufomaculata

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L	0.001				0.001
B - N					
B - L					
C - N		0.243	0.001		0.244
C - L					

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Pisolithus tinctoris

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N					
B - L					
C - N		0.010			0.010
C - L					

Pseudotomentella tristis

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.584	0.584
A - L			0.032	0.025	0.057
B - N					
B - L					
C - N					
C - L					

Quercirhiza fibulocystidiata

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.002	0.024	0.849	0.875
A - L	0.063	0.098	0.518	0.915	1.594
B - N	0.004	0.003	0.092	0.177	0.276
B - L		0.011	0.029	0.028	0.068
C - N			0.001	0.066	0.067
C - L	0.017		0.017		0.034

Quercirhiza squamosa

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.344	0.266	1.534	0.395	2.539
A - L	0.302	0.021	0.044	0.114	0.481
B - N	0.009	0.007	0.278	0.009	0.303
B - L	0.052		0.050	0.017	0.119
C - N			0.516	0.02	0.536
C - L	0.002		0.001	0.103	0.106

Quercirhiza sublutea

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.117	0.091	0.208
A - L			0.002	0.076	0.078
B - N					
B - L					
C - N					
C - L					

Russula acrifolia

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.097	0.001	0.098
A - L	1.419	0.017	0.233	0.634	2.303
B - N					
B - L		0.016			0.016
C - N					
C - L					

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Russula acris

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.027	0.027
A - L				0.290	0.290
B - N					
B - L					
C - N					
C - L					

Russula feuginea

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.004	0.015	0.189	0.208
A - L			0.001		0.001
B - N					
B - L					
C - N					
C - L					

Russula firmula

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.001	0.001
A - L	0.003			0.001	0.004
B - N	0.009			0.001	0.010
B - L				0.034	0.034
C - N				0.001	0.001
C - L					

Russula illota

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L		0.016			0.016
B - N					
B - L					
C - N					
C - L					

Russula mairei

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.005	0.001	0.006
A - L			0.002	0.004	0.006
B - N			0.013		0.013
B - L					
C - N	0.007				0.007
C - L					

Russula orcholeuca

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.001		0.001	0.152	0.154
A - L		0.173		0.639	0.812
B - N					
B - L					
C - N					
C - L					

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Russula xerampelina

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N					
B - L					
C - N			0.007		0.007
C - L					

Suillis bovinis

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N					
B - L		0.005			0.005
C - N					
C - L					

Suillis flavius

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N				0.019	0.019
B - L					
C - N					
C - L					

Tetraberlineaerhiza bicolor

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L		0.012			0.012
B - N			0.014		0.014
B - L		0.078			0.078
C - N					
C - L					

Tomentella albomarginata

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L				0.010	0.010
B - N					
B - L					
C - N					
C - L					

Tomentella ferruginea

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.063		0.650	0.713
A - L	0.271	0.003		0.607	0.881
B - N					
B - L	0.002				0.002
C - N					
C - L	0.001			0.001	0.002

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Tuber aestivum

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.013			0.013
A - L					
B - N					
B - L					
C - N					
C - L					

Tuber melanosporum

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.930	0.055	0.004	0.021	1.010
A - L				0.081	0.081
B - N	0.013		0.015		0.028
B - L	0.125		0.024		0.149
C - N	0.132	0.017	0.002		0.151
C - L					

Tuber mesentericum

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.002	0.002
A - L	0.005		0.001		0.006
B - N			0.010		0.010
B - L	0.006		0.001		0.007
C - N		0.001			0.001
C - L					

Tuber puberulum

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.006			0.008	0.014
A - L	0.010	0.042	0.072	0.016	0.140
B - N					
B - L				0.004	0.004
C - N					
C - L	0.011		0.001		0.012

Tuber rufum

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.830	0.150	0.050	0.023	1.053
A - L	0.342		0.014	0.018	0.374
B - N			0.004		0.004
B - L					
C - N				0.001	0.001
C - L					

Tuber unknown - A

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.002		0.002
A - L			0.001		0.001
B - N					
B - L					
C - N	0.082		0.001		0.083
C - L					

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Tuber unknown B

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L			0.009		0.009
B - N	0.037		0.011		0.048
B - L			0.001		0.001
C - N					
C - L					

Tuber unknown C
(yellow (Sulfur) mantle)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N					
B - L					
C - N			0.024		0.024
C - L					

Tuber unknown D

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L		0.001			0.001
B - N	0.023	0.022			0.045
B - L					
C - N					
C - L					

Unknown - Bicolorata
(black mantle with irregular white tip)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.029		0.029
A - L			0.463		0.463
B - N			0.001		0.001
B - L			0.033		0.033
C - N			0.001	0.001	0.002
C - L				0.009	0.009

Unknown - Br & Br
(brown mantle with brown rhizomorph)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L					
B - N			0.002	0.001	0.003
B - L					
C - N				0.002	0.002
C - L					

Unknown - Br & clear
(Brown tip with thick clear mantle)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.108	0.004	0.112
A - L			0.151	0.051	0.202
B - N	0.009	0.002	0.037	0.001	0.049
B - L			0.316	0.136	0.452
C - N					
C - L					

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Unknown - Brown & Black
(Probable older necrotic version of Unknown - Br & Br)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.190		0.190
A - L					
B - N					
B - L					
C - N					
C - L					

Unknown - Gray
(Gray smooth mantle but does not look old)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.415	0.415
A - L				0.327	0.327
B - N					
B - L					
C - N					
C - L					

Unkown - Gray & cystidia
(Gray mantle covered with fine clear cystidia)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N					
A - L			0.013		0.013
B - N					
B - L					
C - N					
C - L					

Unknown - P
(Probable older version of Piceirhiza glutinosa)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.096	0.096
A - L				0.352	0.352
B - N					
B - L					
C - N					
C - L					

Unknown - Q
(Black like Quercirhiza but fewer emanating hyphae)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N				0.001	0.001
A - L					
B - N					
B - L					
C - N					
C - L					

Unknown - Rosa
(Rose tint under mantle)

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.104	0.177	0.281
A - L			0.011	0.028	0.039
B - N	0.204		0.087	0.034	0.325
B - L			0.036	0.08	0.116
C - N			0.125	0.009	0.134
C - L			0.001	0.003	0.004

Appendix 8B: Mycorrhizal species isolated from unlimed (N) and limed (L) soils from 0-10 cm (A), 30-40 cm (B) and 50-60 cm (C) depth from an oak forest in Merzalben, Rheinland-Pflaz, Germany

Xerocomus badius

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N	0.389	0.014	0.001		0.404
A - L		0.050			0.050
B - N					
B - L					
C - N					
C - L					

Xerocomus chrysenteron

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N		0.006	0.771	0.374	1.151
A - L	0.001		0.017	0.134	0.152
B - N			0.002	0.001	0.003
B - L			0.011	0.004	0.015
C - N			0.011		0.011
C - L	0.001			0.006	0.007

Xerocomus submentosus

	Spring 1999	Fall 1999	Spring 2000	Fall 2000	Total
A - N			0.017		0.017
A - L		0.002	0.007		0.009
B - N			0.001		0.001
B - L					
C - N				0.027	0.027
C - L					

Appendix 9: Physical Parameters Affecting Growth

Appendix 9A: Moisture Content of Unlimed and Limed Soils

- **Table 9A-1: Moisture of unlimed soils at 0-10 cm depth**
- **Table 9A-2: Moisture of unlimed soils at 30-40 cm depth**
- **Table 9A-3: Moisture of unlimed soils at 50-60 cm depth**
- **Table 9A-4: Moisture of limed soils at 0-10 cm depth**
- **Table 9A-5: Moisture of limed soils at 30-40 cm depth**
- **Table 9A-6: Moisture of limed soils at 50-60 cm depth**
- **Table 9A-7: Significance of Liming**
- **Table 9A-8: Significance of Depth**

Appendix 9B: pH of Unlimed and Limed Soils

- **Table 9B-1: pH Tests for unlimed soils from various depths**
- **Table 9B-2: pH Tests for limed soils from various depths**
- **Table 9B-3: pH Pre-tests of wet and dried soil samples**

Appendix 9C: Gram Weights of Mycorrhizal and Non-mycorrhizal Roots

- **Table 9C-1: Horizon A (0-10 cm)**
- **Table 9C-2: Horizon B (30-40 cm)**
- **Table 9C-3: Horizon C (50-60 cm)**
- **Table 9C-4: Spring 1999**
- **Table 9C-5: Fall 1999**
- **Table 9C-6: Spring 2000**
- **Table 9C-7: Fall 2000**

Appendix 9D: Statistical Analysis Formulas

- **9D-1: Calculating Significant Differences: Student T Test**
- **9D-2: Standard Deviation, Average, Mean, Mode**
- **9D-3: Exponential Growth, Carrying Capacity, Successive Populations**
- **9D-4: Environmental Resistance**

Appendix 9: Moisture content of unlimed and limed roots

Table 9A-1: Moisture of UNLIMED Soils in grams at 0-10 cm depth

Spring 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	Spring 1999 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
1 N 0-10	102.20	75.00	297.20	271.28	25.92	1 N 0-10	75.00	49.08	25.92	35%
2 N 0-10	101.70	75.00	260.10	236.56	23.54	2 N 0-10	75.00	51.46	23.54	31%
3 N 0-10	102.50	75.00	274.00	255.82	18.18	3 N 0-10	75.00	56.82	18.18	24%
4 N 0-10	102.50	75.00	283.50	262.89	20.61	4 N 0-10	75.00	54.39	20.61	27%
5 N 0-10	102.40	75.00	302.70	285.39	17.31	5 N 0-10	75.00	57.69	17.31	23%
6 N 0-10	102.70	75.00	299.80	285.01	14.79	6 N 0-10	75.00	60.21	14.79	20%
						Total	**450.00**	**329.65**	**120.35**	**160%**
						Average	**75.00**	**54.94**	**20.06**	**27%**

Fall 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	Fall 1999 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
7 N 0-10	102.70	75.00	259.50	250.82	8.68	7 N 0-10	75.00	66.32	8.68	12%
8 N 0-10	102.50	75.00	296.80	281.83	14.97	8 N 0-10	75.00	60.03	14.97	20%
9 N 0-10	159.80	75.00	279.50	253.69	25.81	9 N 0-10	75.00	49.19	25.81	34%
10 N 0-10	165.50	75.00	295.20	278.33	16.87	10 N 0-10	75.00	58.13	16.87	22%
11 N 0-10	185.20	75.00	334.60	322.90	11.70	11 N 0-10	75.00	63.30	11.70	16%
12 N 0-10	189.20	75.00	294.00	281.45	12.55	12 N 0-10	75.00	62.45	12.55	17%
						Total	**450.00**	**359.42**	**90.58**	**121%**
						Average	**75.00**	**59.90**	**15.10**	**20%**

Spring 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	Spring 2000 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
100 N 0-10	101.20	75.00	167.20	154.35	12.85	100 N 0-10	75.00	62.15	12.85	17%
200 N 0-10	101.40	75.00	170.90	152.92	17.98	200 N 0-10	75.00	57.02	17.98	24%
300 N 0-10	101.10	75.00	169.30	156.21	13.09	300 N 0-10	75.00	61.91	13.09	17%
400 N 0-10	101.30	75.00	197.40	177.17	20.23	400 N 0-10	75.00	54.77	20.23	27%
500 N 0-10	100.30	75.00	298.50	280.83	17.67	500 N 0-10	75.00	57.33	17.67	24%
600 NB 0-10	100.00	75.00	168.10	152.45	15.65	600 NB 0-10	75.00	59.35	15.65	21%
						Total	**450.00**	**352.53**	**97.47**	**130%**
						Average	**75.00**	**58.76**	**16.25**	**22%**

Fall 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	Fall 2000 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
700 N 0-10	99.90	75.00	171.30	145.92	25.38	700 N 0-10	75.00	49.62	25.38	34%
800 N 0-10	99.80	75.00	299.30	278.26	21.04	800 N 0-10	75.00	53.96	21.04	28%
900 N 0-10	97.00	75.00	297.70	279.57	18.13	900 N 0-10	75.00	56.87	18.13	24%
1000 N 0-10						1000 N 0-10				
1100 N 0-10	100.00	75.00	144.90	126.83	18.07	1100 N 0-10	75.00	56.93	18.07	24%
1200 N 0-10	99.80	75.00	280.80	267.18	13.62	1200 N 0-10	75.00	61.38	13.62	18%
1300 N 0-10						1300 N 0-10				
1400 N 0-10	100.00	75.00	306.70	286.45	20.25	1400 N 0-10	75.00	54.75	20.25	27%
1500 N 0-10	99.90	75.00	296.80	276.27	20.53	1500 N 0-10	75.00	54.47	20.53	27%
1600 N 0-10	100.00	75.00	175.00	156.60	18.40	1600 N 0-10	75.00	56.60	18.40	25%
						Total	**600.00**	**444.58**	**155.42**	**207%**
						Average	**75.00**	**55.57**	**19.43**	**26%**

Appendix 9: Moisture content of unlimed and limed roots

Table 9A-2: 'Moisture of UNLIMED soils in grams at 30-40 cm depth

Spring 1999 Probe	Original Sample	. Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	Spring 1999 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
1 N 30-40	102.20	60.00	364.30	351.30	13.00	1 N 30-40	60.00	47.00	13.00	22%
2 N 30-40	96.40	60.00	285.80	272.50	13.30	2 N 30-40	60.00	46.70	13.30	22%
3 N 30-40	102.90	60.00	342.60	334.60	8.00	3 N 30-40	60.00	52.00	8.00	13%
4 N 30-40	102.50	60.00	280.50	272.60	7.90	4 N 30-40	60.00	52.10	7.90	13%
5 N 30-40	102.60	60.00	362.50	349.50	13.00	5 N 30-40	60.00	47.00	13.00	22%
6 N 30-40*	102.70	60.00	263.00	259.00	4.00	6 N 30-40*	60.00	56.00	4.00	7%
						Total	**360.00**	**300.80**	**59.20**	**99%**
						Average	**60.00**	**50.13**	**9.87**	**16%**

Fall 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	Fall 1999 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
7 N 30-40	102.80	60.00	298.50	293.80	4.70	7 N 30-40	60.00	55.30	4.70	8%
8 N 30-40*	102.70	60.00	280.00	273.10	6.90	8 N 30-40*	60.00	53.10	6.90	12%
9 N 30-40*	213.00	60.00	264.10	257.60	6.50	9 N 30-40*	60.00	53.50	6.50	11%
10 N 30-40	208.70	60.00	216.30	209.20	7.10	10 N 30-40	60.00	52.90	7.10	12%
11 N 30-40*	218.70	60.00	342.50	335.40	7.10	11 N 30-40*	60.00	52.90	7.10	12%
12 N 30-40*	221.70	60.00	295.20	289.10	6.10	12 N 30-40*	60.00	53.90	6.10	10%
						Total	**360.00**	**321.60**	**38.40**	**64%**
						Average	**60.00**	**53.60**	**6.40**	**11%**

Spring 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	Spring 2000 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
100 N 30-40	100.90	60.00	280.00	273.30	6.70	100 N 30-40	60.00	53.30	6.70	11%
200 N 30-40	101.10	60.00	285.50	281.80	3.70	200 N 30-40	60.00	56.30	3.70	6%
300 N 30-40*	100.00	60.00	267.50	262.90	4.60	300 N 30-40*	60.00	55.40	4.60	8%
400 NC 30-40	95.80	60.00	343.90	337.00	6.90	400 NC 30-40	60.00	53.10	6.90	12%
500 N 30-40	100.00	60.00	281.40	275.80	5.60	500 N 30-40	60.00	54.40	5.60	9%
600 NB 30-40	100.00	60.00	285.00	274.60	10.40	600 NB 30-40	60.00	49.60	10.40	17%
						Total	**360.00**	**322.10**	**37.90**	**63%**
						Average	**60.00**	**53.68**	**6.32**	**11%**

Fall 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	Fall 2000 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
700 ND 30-40	99.80	60.00	269.00	260.80	8.20	700 ND 30-40	60.00	51.80	8.20	14%
800 NB 30-40	100.00	60.00	274.60	265.80	8.80	800 NB 30-40	60.00	51.20	8.80	15%
900 NC 30-40	100.00	60.00	267.70	258.60	9.10	900 NC 30-40	60.00	50.90	9.10	15%
1000 N 30-40						1000 N 30-40				
1100 NC 30-4(	99.90	60.00	209.90	201.00	8.90	1100 NC 30-4(	60.00	51.10	8.90	15%
1200 N 30-40	99.60	60.00	254.30	246.30	8.00	1200 N 30-40	60.00	52.00	8.00	13%
1300 N 30-40						1300 N 30-40				
1400 N 30-40	100.20	60.00	292.70	281.50	11.20	1400 N 30-40	60.00	48.80	11.20	19%
1500 N 30-40						1500 N 30-40				
1600 N 30-40	99.80	60.00	255.40	248.60	6.80	1600 N 30-40	60.00	53.20	6.80	11%
						Total	**420.00**	**359.00**	**61.00**	**102%**
						Average	**60.00**	**51.29**	**8.71**	**15%**

Appendix 9: Moisture content of unlimed and limed roots

Table 9A-3: Moisture Content of UNLIMED soils in grams at 50-60 cm depth

Spring 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
1 N 50-60	102.10	60.00	251.00	236.30	14.70
2 N 50-60	102.50	60.00	275.20	258.80	16.40
3 N 50-60	102.50	60.00	324.90	311.40	13.50
4 N 50-60	102.30	60.00	293.30	280.90	12.40
5 N 50-60	102.50	60.00	261.90	250.90	11.00
6 N 50-60	102.70	60.00	288.00	277.60	10.40

Spring 1999 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
1 N 50-60	60.00	45.30	14.70	25%
2 N 50-60	60.00	43.60	16.40	27%
3 N 50-60	60.00	46.50	13.50	23%
4 N 50-60	60.00	47.60	12.40	21%
5 N 50-60	60.00	49.00	11.00	18%
6 N 50-60	60.00	49.60	10.40	17%
Total	**360.00**	**281.60**	**78.40**	**131%**
Average	**60.00**	**46.93**	**13.07**	**22%**

Fall 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
7 N 50-60	102.80	60.00	261.90	251.50	10.40
8 N 50-60*	102.40	60.00	290.60	281.10	9.50
9 N 50-60*	229.80	60.00	276.50	264.10	12.40
10 N 50-60	239.70	60.00	288.80	276.90	11.90
11 N 50-50	195.60	60.00	286.30	274.20	12.10
12 N 50-60	214.70	60.00	286.20	276.20	10.00

Fall 1999 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
7 N 50-60	60.00	49.60	10.40	17%
8 N 50-60*	60.00	50.50	9.50	16%
9 N 50-60*	60.00	47.60	12.40	21%
10 N 50-60	60.00	48.10	11.90	20%
11 N 50-50	60.00	47.90	12.10	20%
12 N 50-60	60.00	50.00	10.00	17%
Total	**360.00**	**293.70**	**66.30**	**111%**
Average	**60.00**	**48.95**	**11.05**	**18%**

Spring 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
100 NB 50-60	101.10	60.00	288.20	276.50	11.70
200 N 50-60	100.00	60.00	236.00	225.70	10.30
300 N 50-60*	99.30	60.00	272.60	264.50	8.10
400 NB 50-60	99.40	60.00	305.30	294.70	10.60
500 NB 50-60	99.40	60.00	284.40	270.50	13.90
600 NB 50-60	99.30	60.00	264.60	245.90	18.70

Spring 2000 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
100 NB 50-60	60.00	48.30	11.70	20%
200 N 50-60	60.00	49.70	10.30	17%
300 N 50-60*	60.00	51.90	8.10	14%
400 NB 50-60	60.00	49.40	10.60	18%
500 NB 50-60	60.00	46.10	13.90	23%
600 NB 50-60	60.00	41.30	18.70	31%
Total	**360.00**	**286.70**	**73.30**	**122%**
Average	**60.00**	**47.78**	**12.22**	**20%**

Fall 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
700 ND 50-60	99.80	60.00	328.70	313.30	15.40
800 ND 50-60	100.00	60.00	344.10	330.30	13.80
900 NC 50-60	99.90	60.00	282.00	268.90	13.10
1000 ND 50-6(	99.90	60.00	333.50	317.90	15.60
1100 N 50-60	99.60	60.00	343.00	331.50	11.50
1200 NB 50-6(	99.50	60.00	272.30	259.40	12.90
1300 N 50-60					
1400 N 50-60					
1500 N 50-60					
1600 NB 50-6(	99.80	60.00	250.60	237.50	13.10

Fall 2000 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
700 ND 50-60	60.00	44.60	15.40	26%
800 ND 50-60	60.00	46.20	13.80	23%
900 NC 50-60	60.00	46.90	13.10	22%
1000 ND 50-6(	60.00	44.40	15.60	26%
1100 N 50-60	60.00	48.50	11.50	19%
1200 NB 50-6(	60.00	47.10	12.90	22%
1300 N 50-60				
1400 N 50-60				
1500 N 50-60				
1600 NB 50-6(	60.00	46.90	13.10	22%
Total	**420.00**	**324.60**	**95.40**	**159%**
Average	**60.00**	**46.37**	**13.63**	**23%**

Appendix 9: Moisture content of unlimed and limed roots

Table 9A-4: Moisture of LIMED soils in grams at 0-10 cm depth

Spring 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	**Spring 1999** Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
1 K 0-10	102.10	60.00	282.20	267.00	15.20	1 K 0-10	60.00	44.80	15.20	25%
2 K 0-10	102.40	60.00	283.60	262.91	20.69	2 K 0-10	60.00	39.31	20.69	34%
3 K 0-10	102.20	60.00	216.20	198.15	18.05	3 K 0-10	60.00	41.95	18.05	30%
4 K 0-10	102.20	60.00	281.40	264.38	17.02	4 K 0-10	60.00	42.98	17.02	28%
5 K 0-10	102.40	60.00	282.00	268.83	13.17	5 K 0-10	60.00	46.83	13.17	22%
6 K 0-10	102.60	60.00	181.90	175.24	6.66	6 K 0-10	60.00	53.34	6.66	11%
						Total	**360.00**	**269.21**	**90.79**	**151%**
						Average	**60.00**	**44.87**	**15.13**	**25%**

Fall 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	**Fall 1999** Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
7 K 0-10	102.40	60.00	295.10	284.29	10.81	7 K 0-10	60.00	49.19	10.81	18%
8 K 0-10	191.30	60.00	281.60	272.15	9.45	8 K 0-10	60.00	50.55	9.45	16%
9 K 0-10	184.40	60.00	291.70	282.56	9.14	9 K 0-10	60.00	50.86	9.14	15%
10 K 0-10*	142.90	60.00	267.50	259.92	7.58	10 K 0-10*	60.00	52.42	7.58	13%
11 K 0-10	189.30	60.00	318.90	308.07	10.83	11 K 0-10	60.00	49.17	10.83	18%
12 K 0-10	100+	60.00	280.30	271.47	8.83	12 K 0-10	60.00	51.17	8.83	15%
						Total	**360.00**	**303.36**	**56.64**	**94%**
						Average	**60.00**	**50.56**	**9.44**	**16%**

Spring 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	**Spring 2000** Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
100 K 0-10	100.40	60.00	287.30	276.86	10.44	100 K 0-10	60.00	49.56	10.44	17%
200 K 0-10	100.80	60.00	262.10	250.21	11.89	200 K 0-10	60.00	48.11	11.89	20%
300 KB 0-10	99.20	60.00	270.00	254.52	15.48	300 KB 0-10	60.00	44.52	15.48	26%
400 K 0-10	99.00	60.00	245.10	232.69	12.41	400 K 0-10	60.00	47.59	12.41	21%
500 K 0-10	99.10	60.00	284.10	269.91	14.19	500 K 0-10	60.00	45.81	14.19	24%
600 KC 0-10	99.30	60.00	280.50	266.56	13.94	600 KC 0-10	60.00	46.06	13.94	23%
						Total	**360.00**	**281.65**	**78.35**	**131%**
						Average	**60.00**	**46.94**	**13.06**	**22%**

Fall 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference	**Fall 2000** Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
700 K 0-10						700 K 0-10				
800 K 0-10	99.10	60.00	280.30	266.78	13.52	800 K 0-10	60.00	46.48	13.52	23%
900 K 0-10	99.20	60.00	279.80	262.59	17.21	900 K 0-10	60.00	42.79	17.21	29%
1000 K 0-10	99.10	60.00	255.20	234.80	20.40	1000 K 0-10	60.00	39.60	20.40	34%
1100 K 0-10	99.90	60.00	269.10	254.82	14.28	1100 K 0-10	60.00	45.72	14.28	24%
1100 KE 0-10	99.80	60.00	254.00	237.64	16.36	1100 KE 0-10	60.00	43.64	16.36	27%
1200 K 0-10	100.50	60.00	274.40	258.79	15.61	1200 K 0-10	60.00	44.39	15.61	26%
1300 K 0-10						1300 K 0-10				
1400 K 0-10	99.90	60.00	263.50	249.35	14.15	1400 K 0-10	60.00	45.85	14.15	24%
						Total	**420.00**	**308.47**	**111.53**	**186%**
						Average	**60.00**	**44.07**	**15.93**	**27%**

Appendix 9: Moisture content of unlimed and limed roots

Table 9A-5: Moisture of LIMED soils in grams at 30-40 cm depth

Spring 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
1 K 30-40*	102.20	60.00	258.50	249.50	9.00
2 K 30-40	70.90	60.00	275.90	265.30	10.60
3 K 30-40*	61.50	60.00	254.10	241.80	12.30
4 K 30-40	102.30	60.00	229.90	219.00	10.90
5 K 30-40	102.50	60.00	244.50	235.20	9.30
6 K 30-40	102.20	60.00	266.70	261.20	5.50

Spring 1999 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
1 K 30-40*	60.00	51.00	9.00	15%
2 K 30-40	60.00	49.40	10.60	18%
3 K 30-40*	60.00	47.70	12.30	21%
4 K 30-40	60.00	49.10	10.90	18%
5 K 30-40	60.00	50.70	9.30	16%
6 K 30-40	60.00	54.50	5.50	9%
Total	**360.00**	**302.40**	**57.60**	**96%**
Average	**60.00**	**50.40**	**9.60**	**16%**

Fall 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
7 K 30-40	102.60	60.00	254.10	248.10	6.00
8 K 30-40	102.60	60.00	264.00	257.20	6.80
9 K 30-40	205.20	60.00	298.30	291.70	6.60
10 K 30-40	237.60	60.00	342.40	337.70	4.70
11 K 30-40*	191.10	60.00	337.00	329.50	7.50
12 K 30-40	211.10	60.00	290.30	282.10	8.20

Fall 1999 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
7 K 30-40	60.00	54.00	6.00	10%
8 K 30-40	60.00	53.20	6.80	11%
9 K 30-40	60.00	53.40	6.60	11%
10 K 30-40	60.00	55.30	4.70	8%
11 K 30-40*	60.00	52.50	7.50	13%
12 K 30-40	60.00	51.80	8.20	14%
Total	**360.00**	**320.20**	**39.80**	**66%**
Average	**60.00**	**53.37**	**6.63**	**11%**

Spring 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
100 K 30-40	100.90	60.00	292.50	284.70	7.80
200 KB 30-40	101.00	60.00	284.90	276.80	8.10
300 KB 30-40	99.80	60.00	285.40	276.60	8.80
400 KB 30-40	99.80	60.00	279.70	271.50	8.20
500 KB 30-40	99.90	60.00	337.60	329.90	7.70
600 KB 30-40	100.00	60.00	280.30	267.80	12.50

Spring 2000 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
100 K 30-40	60.00	52.20	7.80	13%
200 KB 30-40	60.00	51.90	8.10	13%
300 KB 30-40	60.00	51.20	8.80	15%
400 KB 30-40	60.00	51.80	8.20	14%
500 KB 30-40	60.00	52.30	7.70	13%
600 KB 30-40	60.00	47.50	12.50	21%
Total	**360.00**	**306.90**	**53.10**	**88%**
Average	**60.00**	**51.15**	**8.85**	**15%**

Fall 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
700 K 30-40					
800 KB 30-40	99.80	60.00	278.20	270.50	7.70
900 KC 30-40	99.80	60.00	268.80	259.90	8.90
1000 KC 30-4	99.90	60.00	343.60	333.70	9.90
1100 K 30-40	100.20	60.00	322.10	312.80	9.30
1100 KE 30-4	99.90	60.00	284.80	275.80	9.00
1200 KC 30-4	100.00	60.00	284.60	274.90	9.70
1300 K 30-40					
1400 KB 30-4	99.70	60.00	277.30	270.30	7.00

Fall 2000 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
700 K 30-40				
800 KB 30-40	60.00	52.30	7.70	13%
900 KC 30-40	60.00	51.10	8.90	15%
1000 KC 30-4	60.00	50.10	9.90	17%
1100 K 30-40	60.00	50.70	9.30	16%
1100 KE 30-4	60.00	51.00	9.00	15%
1200 KC 30-4	60.00	50.30	9.70	16%
1300 K 30-40				
1400 KB 30-4	60.00	53.00	7.00	12%
Total	**420.00**	**358.50**	**61.50**	**103%**
Average	**60.00**	**51.21**	**8.79**	**15%**

Appendix 9: Moisture content of unlimed and limed roots

Table 9A-6: Moisture of LIMED soils in grams at 50-60 cm depth

Spring 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
1 K 50-60	102.30	60.00	214.90	200.20	14.70
2 K 50-60	102.40	60.00	158.30	137.90	20.40
3 K 50-60	102.40	60.00	396.80	378.20	18.60
4 K 50-60*	102.30	60.00	271.50	253.50	18.00
5 K 50-60	102.60	60.00	287.50	273.40	14.10
6 K 50-60*					

Spring 1999 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
1 K 50-60	60.00	45.30	14.70	25%
2 K 50-60	60.00	39.60	20.40	34%
3 K 50-60	60.00	41.40	18.60	31%
4 K 50-60*	60.00	42.00	18.00	30%
5 K 50-60	60.00	45.90	14.10	24%
6 K 50-60*				
Total	**300.00**	**214.20**	**85.80**	**143%**
Average	**60.00**	**42.84**	**17.16**	**29%**

Fall 1999 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
7 K 50-60	102.70	60.00	285.50	275.90	9.60
8 K 50-60	102.60	60.00	161.50	154.50	7.00
9 K 50-60*	244.70	60.00	324.20	314.70	9.50
10 K 50-60*	245.20	60.00	332.60	324.10	8.50
11 K 50-60*	213.90	60.00	187.10	176.40	10.70
12 K 50-60	215.80	60.00	158.80	146.60	12.20

Fall 1999 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
7 K 50-60	60.00	50.40	9.60	16%
8 K 50-60	60.00	53.00	7.00	12%
9 K 50-60*	60.00	50.50	9.50	16%
10 K 50-60*	60.00	51.50	8.50	14%
11 K 50-60*	60.00	49.30	10.70	18%
12 K 50-60	60.00	47.80	12.20	20%
Total	**360.00**	**302.50**	**57.50**	**96%**
Average	**60.00**	**50.42**	**9.58**	**16%**

Spring 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
100 KB 50-60	101.00	60.00	286.60	275.70	10.90
200 KB 50-60	101.40	60.00	300.30	289.50	10.80
300 KB 50-60	99.80	60.00	252.60	244.50	8.10
400 KB 50-60	99.90	60.00	287.10	278.00	9.10
500 KB 50-60	101.30	60.00	369.20	358.80	10.40
600 K 50-60	99.80	60.00	288.80	276.40	12.40

Spring 2000 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
100 KB 50-60	60.00	49.10	10.90	18%
200 KB 50-60	60.00	49.20	10.80	18%
300 KB 50-60	60.00	51.90	8.10	14%
400 KB 50-60	60.00	50.90	9.10	15%
500 KB 50-60	60.00	49.60	10.40	17%
600 K 50-60	60.00	47.60	12.40	21%
Total	**360.00**	**298.30**	**61.70**	**103%**
Average	**60.00**	**49.72**	**10.28**	**17%**

Fall 2000 Probe	Original Sample	Soil tested	Wet Weight with glass	Dry Weight with glass	Difference
700 K 50-60					
800 KB 50-60	100.00	60.00	347.60	335.40	12.20
900 KC 50-60	100.00	60.00	300.30	288.90	11.40
1000 KC 50-6	99.80	60.00	286.70	273.50	13.20
1100 KB 50-6	100.00	60.00	326.00	311.20	14.80
1100 KE 50-6	99.90	60.00	368.10	352.80	15.30
1200 KE 50-6	100.00	60.00	287.10	276.00	11.10
1300 K 50-60					
1400 KB 50-6	99.90	60.00	221.40	209.10	12.30

Fall 2000 Probe	Wet Soil grams	Dry Soil grams	Difference grams	Water %
700 K 50-60				
800 KB 50-60	60.00	47.80	12.20	20%
900 KC 50-60	60.00	48.60	11.40	19%
1000 KC 50-6	60.00	46.80	13.20	22%
1100 KB 50-6	60.00	45.20	14.80	25%
1100 KE 50-6	60.00	44.70	15.30	26%
1200 KE 50-6	60.00	48.90	11.10	19%
1300 K 50-60				
1400 KB 50-6	60.00	47.70	12.30	21%
Total	**420.00**	**329.70**	**90.30**	**151%**
Average	**60.00**	**47.10**	**12.90**	**22%**

Appendix 9A : Moisture content of unlimed and limed roots

Table 9A-7: Significance of Liming. Summary of average % moisture content of unlimed and limed soils at various depths and seasons. T-test used to determine significant differences between samples where N = Not Significant, S = Significant, HS = Highly Significant.

Depths	0-10 cm	0-10 cm	30-40 cm	30-40 cm	50-60 cm	50-60 cm
Spring 1999	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
	35%	25%	22%	15%	25%	25%
	31%	34%	22%	18%	27%	34%
	24%	30%	13%	21%	23%	31%
	27%	28%	13%	18%	21%	30%
	23%	22%	22%	16%	18%	24%
	20%	11%	7%	9%	17%	
Total	160%	150%	99%	97%	131%	144%
Ave.	27%	25%	17%	16%	22%	29%
t-test	**28%**	**N**	**45%**	**N**	**1%**	**HS**
Fall 1999	12%	18%	8%	10%	17%	16%
	20%	16%	12%	11%	16%	12%
	34%	15%	11%	11%	21%	16%
	22%	13%	12%	8%	20%	14%
	16%	18%	12%	13%	20%	18%
	17%	15%	10%	14%	17%	20%
Total	121%	95%	65%	67%	111%	96%
Ave	20%	16%	11%	11%	19%	16%
t-test	**14%**	**N**	**39%**	**N**	**6%**	**S**
Spring 2000	17%	17%	11%	13%	20%	18%
	24%	20%	6%	13%	17%	18%
	17%	26%	8%	15%	14%	14%
	27%	21%	12%	14%	18%	15%
	24%	24%	9%	13%	24%	17%
	21%	23%	17%	21%	31%	21%
Total	130%	131%	63%	89%	124%	103%
Ave.	22%	22%	11%	15%	21%	17%
t-test	**47%**	**N**	**0%**	**HS**	**5%**	**S**
Fall 2000	34%					
	28%	23%	14%	13%	26%	20%
	24%	29%	15%	15%	23%	19%
	24%	34%	15%	17%	22%	22%
	18%	24%	15%	16%	26%	25%
	27%	27%	13%	15%	19%	26%
	27%	26%	19%	16%	22%	19%
	25%	24%	11%	12%	22%	21%
Total	207%	187%	102%	104%	160%	152%
Ave	26%	27%	15%	15%	23%	22%
t-test	**17%**	**N**	**34%**	**N**	**25%**	**N**

Sample Formula: t-test (B38:B44,C38:C44,1,1) Using computer statistics program

t-test	0.172516201	17% = N	0.344526113	34% = N	0.246363123	25% = N
tinv/df12	1.450628133		0.984028929		1.218731995	

Appendix 9A: Moisture of unlimed and limed soils

Table 9A-8: Significance of Depth. Comparisons between Horizons (A:B), (B:C) and (A:C).
Horizon A = 0-10 cm depth, Horizon B = 30-40 cm depth, Horizon C = 50-60 cm depth
SD = Significant Differences, 'N = Not Significant, S = Significant, HS = Highly Significant

		Unlimed			
Depths	Season	t-tests	tinv	df	**Significant Differences**
A:B	Spring 1999	0.00180478	4.20826836	10	**HS**
	Fall 1999	0.01167320	3.07834853	10	**HS**
	Spring 2000	0.00233073	4.04805178	10	**HS**
	Fall 2000	0.00233073	3.84505256	12	**HS**
B:C	Spring 1999	0.02932768	2.54070983	10	**S**
	Fall 1999	0.00013470	5.98607585	10	**HS**
	Spring 2000	0.00067236	4.84928023	10	**HS**
	Fall 2000	0.00025933	5.10597602	12	**HS**
A:C	Spring 1999	0.00588974	3.48318281	10	**HS**
	Fall 1999	0.27969170	1.14293243	10	**N**
	Spring 2000	0.36956252	0.93960239	10	**N**
	Fall 2000	0.17948871	1.42554882	12	**N**

		Limed			
Depths	Season	t-tests	tinv	df	**SD**
A:B	Spring 1999	0.00282215	3.92959919	10	**HS**
	Fall 1999	0.00191993	4.16941475	10	**HS**
	Spring 2000	0.00262272	3.97485564	10	**HS**
	Fall 2000	0.05299058	2.14631655	12	**N**
B:C	Spring 1999	0.00058690	5.48083335	8	**HS**
	Fall 1999	0.00085702	4.68804501	10	**HS**
	Spring 2000	0.04212076	2.32901584	10	**N**
	Fall 2000	0.00043740	4.79514711	12	**HS**
A:C	Spring 1999	0.39714737	0.89453920	8	**N**
	Fall 1999	0.44954270	0.78698008	10	**N**
	Spring 2000	0.02836326	2.56020940	10	**S**
	Fall 2000	0.08759778	1.85976660	12	**N**

Appendix 9B: pH values of unlimed and limed soils

Table 9B-1:: pH tests for Limed (K) and Unlimed (N) soil samples from 0-10, 30-40 and 50-60 cm depths from Merzablen Oak Forest in spring and fall 1999 and 2000

		pH H2O	pH CaCl2	pH KCl		pH H2O	pH CaCl2	pH KCl		pH H2O	pH CaCl2	pH KCl
Spring 1999	1 N 0-10	3,78	3,26	3,23	1 N 30-40	4,45	4,08	4,10	1 N 50-60	4,60	4,37	4,24
	2 N 0-10	3,95	3,21	3,25	2 N 30-40	5,26	4,73	4,89	2 N 50-60	4,91	4,96	4,39
	3 N 0-10	3,93	3,31	3,33	3 N 30-40	4,73	4,57	4,24	3 N 50-60	5,03	4,53	4,33
	4 N 0-10	3,78	3,11	3,14	4 N 30-40	4,33	4,22	4,26	4 N 50-60	4,96	4,51	4,42
	5 N 0-10	3,77	2,95	3,02	5 N 30-40	4,79	4,46	4,40	5 N 50-60	5,12	4,64	4,40
	6 N 0-10	3,54	2,69	2,75	6 N 30-40*	3,64	3,04	3,07	6 N 50-60	4,75	4,40	4,31
	Total	**22,75**	**18,53**	**18,72**		**27,20**	**25,10**	**24,96**		**29,37**	**27,41**	**26,09**
	Average	**3,79**	**3,09**	**3,12**		**3,79**	**3,09**	**3,12**		**4,90**	**4,57**	**4,35**
Fall 1999	7 N 0-10	3,48	2,73	2,74	7 N 30-40	4,61	3,93	4,09	7 N 50-60	4,83	4,46	4,27
	8 N 0-10 *	3,58	3,00	3,01	8 N 30-40*	4,54	4,25	4,35	8 N 50-60*	4,84	4,41	4,18
	9 N 0-10	3,42	2,90	2,95	9 N 30-40*	4,53	4,22	4,17	9 N 50-60*	4,54	4,42	4,25
	10 N 0-10	3,52	3,03	3,12	10 N 30-40	4,51	4,14	4,18	10 N 50-60	4,55	4,53	4,31
	11 N 0-10	3,78	3,46	3,26	11 N 30-40*	4,52	4,30	4,32	11 N 50-50	4,62	4,40	4,26
	12 N 0-10	3,59	3,07	3,06	12 N 30-40*	4,62	4,27	4,45	12 N 50-60	4,69	4,55	4,44
	Total	**21,37**	**18,19**	**18,14**		**27,33**	**25,11**	**25,56**		**28,07**	**26,77**	**25,71**
	Average	**3,56**	**3,03**	**3,02**		**4,56**	**4,19**	**4,26**		**4,68**	**4,46**	**4,29**
Spring 2000	100 N 0-10	3,83	3,40	3,47	100 N 30-40	4,51	4,43	4,19	100 NB 50-60	4,92	4,40	4,27
	200 N 0-10	3,73	2,88	3,00	200 N 30-40	3,90	3,34	3,28	200 N 50-60	4,81	3,96	4,12
	300 N 0-10	3,76	3,35	3,33	300 N 30-40*	4,44	4,30	4,23	300 N 50-60*	4,84	4,50	4,40
	400 N 0-10	3,68	2,93	2,97	400 NC 30-40	4,47	4,41	4,48	400 NB 50-60	4,67	4,58	4,32
	500 N 0-10	3,38	2,78	2,75	500 N 30-40	4,84	4,28	4,52	500 NB 50-60	4,37	3,95	3,97
	600 NB 0-10	3,69	3,17	3,22	600 NB 30-40	4,60	4,14	4,21	600 NB 50-60	4,67	4,36	4,33
	Total	**22,07**	**18,51**	**18,74**		**26,76**	**24,90**	**24,91**		**28,28**	**25,75**	**25,41**
	Average	**3,68**	**3,09**	**3,12**		**4,46**	**4,15**	**4,15**		**4,71**	**4,29**	**4,24**
Fall 2000	700 N 0-10	3,44	2,95	2,92								
	800 N 0-10	3,41	2,86	2,85	700 ND 30-40	4,56	4,29	4,26	700 ND 50-60	4,49	4,17	4,09
	900 N 0-10	3,63	3,08	3,22	800 NB 30-40	4,59	4,23	4,23	800 ND 50-60	4,70	4,52	4,15
	1100 N 0-10	3,31	2,78	2,91	900 NC 30-40	4,55	4,34	4,20	900 NC 50-60	4,64	4,32	4,30
	1200 N 0-10	3,82	3,21	3,27	1100 NC 30-40	4,43	4,12	4,09	1000 ND 50-60	4,42	4,21	4,17
	1400 N 0-10	3,42	2,68	2,75	1200 N 30-40	4,63	4,42	4,10	1100 N 50-60	4,53	4,14	4,09
	1500 N 0-10	3,50	2,89	2,95	1400 N 30-40	4,10	3,66	3,60	1200 NB 50-60	4,70	4,50	4,44
	1600 N 0-10	3,69	3,14	3,07	1600 N 30-40	4,58	4,24	4,23	1600 NB 50-60	4,70	4,48	4,43
	Total	**28,22**	**23,59**	**23,94**		**31,44**	**29,30**	**28,71**		**32,18**	**30,34**	**29,67**
	Average	**3,53**	**2,95**	**2,99**		**4,49**	**4,19**	**4,10**		**4,60**	**4,33**	**4,24**

Appendix 9B: pH values of unlimed and limed soils

Table 9B-2: pH tests for Limed (K) and Unlimed (N) soil samples from 0-10, 30-40 and 50-60 cm depths from Merzablen Oak Forest in spring and fall 1999 and 2000

		pH H2O	pH CaCl2	pH KCl		pH H2O	pH CaCl2	pH KCl		pH H2O	pH CaCl2	pH KCl
Spring 1999	1 K 0-10	4,69	4,14	4,29	1 K 30-40*	4,69	4,23	4,18				
	2 K 0-10	4,10	3,77	3,74	2 K 30-40	4,53	4,34	4,23	1 K 50-60	4,89	4,28	4,37
	3 K 0-10	4,68	4,19	4,39	3 K 30-40*	4,68	4,27	4,18	2 K 50-60	4,78	4,49	4,47
	4 K 0-10	4,53	3,86	3,88	4 K 30-40	4,70	4,30	4,22	3 K 50-60	4,41	4,38	4,53
	5 K 0-10	4,25	3,67	3,67	5 K 30-40	4,78	4,33	4,28	4 K 50-60*	4,86	4,20	4,52
	6 K 0-10	4,59	3,88	3,92	6 K 30-40	4,78	4,34	4,22	5 K 50-60	4,98	4,40	4,36
	Total	**26,84**	**23,51**	**23,89**		**28,16**	**25,81**	**25,31**		**23,92**	**21,75**	**22,25**
	Average	**4,47**	**3,92**	**3,98**		**4,69**	**4,30**	**4,22**		**4,78**	**4,35**	**4,45**
Fall 1999	7 K 0-10	4,50	3,74	3,90	7 K 30-40	4,90	4,25	4,14	7 K 50-60	4,42	4,14	4,09
	8 K 0-10	4,68	4,04	4,14	8 K 30-40	4,73	4,22	4,08	8 K 50-60	5,00	4,14	4,26
	9 K 0-10	3,95	3,40	3,30	9 K 30-40	4,72	4,24	4,07	9 K 50-60*	4,35	3,83	3,86
	10 K 0-10*	4,19	3,63	3,52	10 K 30-40	4,59	3,91	3,82	10 K 50-60*	4,58	3,73	3,61
	11 K 0-10	4,31	3,82	3,86	11 K 30-40*	4,79	4,29	4,28	11 K 50-60*	4,85	4,28	4,34
	12 K 0-10	4,81	4,07	4,13	12 K 30-40	4,79	4,26	4,16	12 K 50-60	4,74	4,28	4,27
	Total	**26,44**	**22,70**	**22,85**		**28,52**	**25,17**	**24,55**		**27,94**	**24,40**	**24,43**
	Average	**4,41**	**3,78**	**3,81**		**4,75**	**4,20**	**4,09**		**4,66**	**4,07**	**4,07**
Spring 2000	100 K 0-10	4,44	3,92	3,98	100 K 30-40	4,68	4,26	4,12	100 KB 50-60	4,62	4,17	4,05
	200 K 0-10	3,89	3,45	3,46	200 KB 30-40	4,82	4,30	4,18	200 KB 50-60	4,59	4,24	4,22
	300 KB 0-10	3,96	3,50	3,46	300 KB 30-40	4,70	4,19	4,17	300 KB 50-60	4,31	4,28	4,24
	400 K 0-10	4,27	3,82	3,86	400 KB 30-40	4,72	4,19	4,11	400 KB 50-60	4,44	4,31	4,17
	500 K 0-10	4,29	3,92	3,80	500 KB 30-40	4,72	4,32	4,26	500 KB 50-60	4,61	4,32	4,11
	600 KC 0-10	4,69	4,29	4,19	600 KB 30-40	4,63	4,37	4,30	600 K 50-60	4,58	4,14	4,11
	Total	**25,54**	**22,90**	**22,75**		**28,27**	**25,63**	**25,14**		**27,15**	**25,46**	**24,90**
	Average	**4,26**	**3,82**	**3,79**		**4,71**	**4,27**	**4,19**		**4,53**	**4,24**	**4,15**
Fall 2000	800 K 0-10	4,36	4,07	4,06	800 KB 30-40	4,66	4,28	4,12	800 KB 50-60	4,44	4,05	4,15
	900 K 0-10	4,69	4,10	4,07	900 KC 30-40	4,69	4,21	4,06	900 KC 50-60	4,58	4,09	4,02
	1000 K 0-10	4,28	4,01	4,00	1000 KC 30-40	4,38	4,00	3,80	1000 KC 50-60	4,51	3,97	3,90
	1100 K 0-10	4,23	3,82	3,82	1100 K 30-40	4,60	4,30	4,25	1100 KB 50-60	4,48	4,12	4,00
	1100 KE 0-10	4,02	3,50	3,47	1100 KE 30-40	4,73	4,03	4,23	1100 KE 50-60	4,48	4,32	4,18
	1200 K 0-10	4,07	3,54	3,54	1200 KC 30-40	4,87	4,24	4,29	1200 KE 50-60	4,51	4,29	4,18
	1400 K 0-10	4,00	3,42	3,40	1400 KB 30-40	4,72	4,12	406,00	1400 KB 50-60	4,38	4,17	3,93
	Total	**29,65**	**26,46**	**26,36**		**32,65**	**29,18**	**430,75**	**0,00**	**31,38**	**29,01**	**28,36**
	Average	**4,24**	**3,78**	**3,77**		**4,66**	**4,17**	**61,54**	**0,00**	**4,48**	**4,14**	**4,05**

Appendix 9B: pH values of unlimed and limed soils

Table 9B-3: Pre-tests of pH of Wet and Dry Soil Samples

Soil	Wet soil	Dry soil		Wet soil	Dry soil		Wet soil	Dry soil		Soil
pH test	water	water		CaCl2	CaCl2		KCl	KCl		Moisture
	pH	pH	Dif.	pH	pH	Dif.	pH	pH	Dif.	%
7N 0-10	3,65	3,72	0,07	3,45	3,21	-0,24	3,23	3,16	-0,07	14%
8K 0-10	4,26	4,56	0,30	4,34	3,90	-0,44	4,10	3,82	-0,28	12%
12K 0-10	5,40	4,60	**-0,80**	4,40	4,18	**-0,22**	4,35	4,15	**-0,20**	**17%**
7N 30-40	5,54	5,33	-0,21	4,60	4,33	-0,27	4,52	4,30	-0,22	10%
8K 30-40	7,00	5,91	-1,09	4,54	4,12	-0,42	4,02	3,95	-0,07	9%
3K 50-60	6,84	5,34	**-1,50**	4,97	4,58	**-0,39**	5,29	4,48	**-0,81**	**17%**
4K 50-60				5,42	4,32	-1,10	4,95	4,46	**-0,49**	**16%**
8K 50-60	7,00	4,92	-2,08	4,26	4,10	-0,16	4,22	4,02	**-0,20**	**3%**
4N 50-60	6,81	4,82	-1,99	5,12	4,37	-0,75	4,73	4,30	**-0,43**	**16%**
7N 50-60	7,19	5,86	-1,33	4,18	4,12	-0,06	4,27	4,10	**-0,17**	**3%**
Total	53,69	45,06	-8,63	45,28	41,23	-4,05	43,68	40,74	-2,94	117%
Average	**5,97**	**4,51**	**-0,96**	**4,53**	**4,12**	**-0,41**	**4,37**	**4,07**	**-0,29**	**12%**

50-60 cm depth soil probes only									
Soil	**Wet soil**	**Dry soil**		**Wet soil**	**Dry soil**		**Wet soil**	**Dry soil**	
pH Test	**water**	**water**		**CaCl2**	**CaCl2**		**KCl**	**KCl**	
	pH	**pH**	**Dif.**	**pH**	**pH**	**Dif.**	**pH**	**pH**	**Dif.**
4N 50-60	6,81	4,82	-1,99	5,12	4,37	-0,75	4,73	4,30	-0,43
7N 50-60	7,19	5,86	-1,33	4,18	4,12	-0,06	4,27	4,10	-0,17
3K 50-60	6,84	5,34	-1,50	4,97	4,58	-0,39	5,29	4,48	-0,81
4K 50-60				5,42	4,32	-1,10	4,95	4,46	-0,49
8K 50-60	7,00	4,92	-2,08	4,26	4,10	-0,16	4,22	4,02	-0,20
Total	27,84	20,94	-6,9	23,95	21,49	-2,46	23,46	21,36	-2,1
Average	**6,96**	**5,24**	**-1,73**	**4,79**	**4,30**	**-0,49**	**4,69**	**4,27**	**-0,42**

Appendix 9C: Gram Weights of Mycorrhizal and Non-mycorrhizal Roots

Table 9C-1: Horizon A (0-10 cm). Fresh gram weights of roots sorted by diameter & mycorrhizal (Myc) tips. Total = Total weight isolated for each root category for the season. Ave/probe = Average weight per probe Est./Sq.Ha = Estimated volume of root type in grams per square hectar.

		Root Diameters > 5 mm	5<>1 mm	1mm	<< 1mm	Myc	Subtotal Roots only	Total Myc + Roots
Spring 1999								
Limed	Total	1.474	9.284	3.004	4.474	4.551	18.236	22.787
	Ave/probe	0.369	2.321	0.751	1.119	1.138	4.559	5.697
	Est./Sq.Ha	471.680	2970.880	961.280	1431.680	1456.320	5835.520	7291.840
Unlimed	Total	0.000	2.050	0.000	0.533	4.547	2.583	7.130
	Ave/probe	0.000	0.513	0.000	0.133	1.137	0.646	1.783
	Est./Sq.Ha	0.000	656.000	0.000	170.560	1455.040	826.560	2281.600
Fall 1999								
Limed	Total	4.145	3.113	2.318	0.264	1.612	9.840	11.452
	Ave/probe	1.036	0.778	0.580	0.066	0.403	2.460	2.863
	Est./Sq.Ha	1326.400	996.160	741.760	84.480	515.712	3148.800	3664.512
Unlimed	Total	0.881	5.262	3.702	0.712	1.489	10.557	12.046
	Ave/probe	0.220	1.316	0.926	0.178	0.372	2.639	3.012
	Est./Sq.Ha	281.920	1683.840	1184.640	227.840	476.480	3378.240	3854.720
Spring 2000								
Limed	Total	8.058	4.813	4.423	7.682	6.246	24.976	31.222
	Ave/probe	1.343	0.802	0.737	1.280	1.041	4.163	5.204
	Est./Sq.Ha	1719.040	1026.773	943.573	1638.827	1332.480	5328.213	6660.693
Unlimed	Total	2.593	4.127	6.721	9.482	8.694	22.923	31.617
	Ave/probe	0.432	0.688	1.120	1.580	1.449	3.821	5.270
	Est./Sq.Ha	553.173	880.427	1433.813	2022.827	1854.720	4890.240	6744.960
Fall 2000								
Limed	Total	11.123	6.986	6.854	23.598	12.381	48.561	60.942
	Ave/probe	1.854	1.164	1.142	3.933	2.064	8.094	10.157
	Est./Sq.Ha	2372.907	1490.347	1462.187	5034.240	2641.280	10359.680	13000.960
Unlimed	Total	3.544	7.823	6.314	18.173	11.725	35.854	47.579
	Ave/probe	0.591	1.304	1.052	3.029	1.954	5.976	7.930
	Est./Sq.Ha	756.053	1668.907	1346.987	3876.907	2501.333	7648.853	10150.187

Appendix 9C: Gram Weights of Mycorrhizal and Non-mycorrhizal Roots

Table 9C-2: Horizon B (30-40 cm). Fresh gram weights of roots sorted by diameter & mycorrhizal (Myc) tips. Total = Total weight isolated for each root category for the season. Ave/probe = Average weight per probe Est./Sq.Ha = Estimated volume of root type in grams per square hectar.

		Root Diameters > 5 mm	5<>1 mm	1mm	<< 1mm	Myc	Subtotal Roots only	Total Myc + Roots
Spring 1999								
Limed	Total	10.235	10.344	1.543	0.367	0.989	22.489	23.478
	Ave/probe	2.559	2.586	0.386	0.092	0.247	5.622	5.870
	Est./Sq.Ha	3275.200	3310.080	493.760	117.440	316.480	7196.480	7512.960
Unlimed	Total	16.308	11.248	3.726	0.259	1.545	31.541	33.086
	Ave/probe	4.077	2.812	0.932	0.065	0.386	7.885	8.272
	Est./Sq.Ha	5218.560	3599.360	1192.320	82.880	494.400	10093.120	10587.520
Fall 1999								
Limed	Total	5.561	2.655	3.143	0.092	0.887	11.451	12.338
	Ave/probe	1.390	0.664	0.786	0.023	0.222	2.863	3.085
	Est./Sq.Ha	1779.520	849.600	1005.760	29.440	283.840	3664.320	3948.160
Unlimed	Total	5.451	3.884	3.588	0.106	1.071	13.029	14.100
	Ave/probe	1.363	0.971	0.897	0.027	0.268	3.257	3.525
	Est./Sq.Ha	6977.280	4971.520	4592.640	135.680	1370.880	16677.120	18048.000
Spring 2000								
Limed	Total	33.354	8.040	5.796	3.602	2.071	50.792	52.863
	Ave/probe	5.559	1.340	0.966	0.600	0.345	8.465	8.811
	Est./Sq.Ha	42693.120	10291.200	7418.880	4610.560	2650.880	65013.760	67664.640
Unlimed	Total	49.829	14.051	7.518	6.796	2.677	78.194	80.871
	Ave/probe	8.305	2.342	1.253	1.133	0.446	13.032	13.479
	Est./Sq.Ha	10630.187	2997.547	1603.840	1449.813	571.093	16681.387	17252.480
Fall 2000								
Limed	Total	38.778	11.336	2.278	7.607	2.817	59.999	62.816
	Ave/probe	6.463	1.889	0.380	1.268	0.470	10.000	10.469
	Est./Sq.Ha	8272.640	2418.347	485.973	1622.827	600.960	12799.787	13400.747
Unlimed	Total	21.729	13.208	4.524	3.446	1.147	42.907	44.054
	Ave/probe	3.622	2.201	0.754	0.574	0.191	7.151	7.342
	Est./Sq.Ha	4635.520	2817.707	965.120	735.147	244.693	9153.493	9398.187

Appendix 9C: Gram Weights of Mycorrhizal and Non-mycorrhizal Roots

Table 9C-3: Horizon C (50-60 cm). Fresh gram weights of roots sorted by diameter & mycorrhizal (Myc) tips. Total = Total weight isolated for each root category for the season. Ave/probe = Average weight per probe Est./Sq.Ha = Estimated volume of root type in grams per square hectar.

		Root Diameters > 5 mm	5<>1 mm	1mm	<< 1mm	Myc	Subtotal Roots only	Total Myc + Roots
Spring 1999								
Limed	Total	13.819	8.070	1.668	0.167	1.122	23.724	24.846
	Ave/probe	3.455	2.018	0.417	0.042	0.281	5.931	6.212
	Est./Sq.Ha	4422.080	2582.400	533.760	53.440	359.040	7591.680	7950.720
Unlimed	Total	21.857	5.473	1.553	0.136	0.646	29.019	29.665
	Ave/probe	5.464	1.368	0.388	0.034	0.162	7.255	7.416
	Est./Sq.Ha	6994.240	1751.360	496.960	43.520	206.720	9286.080	9492.800
Fall 1999								
Limed	Total	23.884	5.177	0.983	0.137	0.118	30.181	30.299
	Ave/probe	5.971	1.294	0.246	0.034	0.030	7.545	7.575
	Est./Sq.Ha	7642.880	1656.640	314.560	43.840	37.760	9657.920	9695.680
Unlimed	Total	33.738	9.685	8.342	0.169	0.837	51.934	52.771
	Ave/probe	8.435	2.421	2.086	0.042	0.209	12.984	13.193
	Est./Sq.Ha	10796.160	3099.200	2669.440	54.080	267.840	16618.880	16886.720
Spring 2000								
Limed	Total	21.130	11.786	5.347	2.295	0.579	40.558	41.137
	Ave/probe	3.522	1.964	0.891	0.383	0.097	6.760	6.856
	Est./Sq.Ha	4507.733	2514.347	1140.693	489.600	123.520	8652.373	8775.893
Unlimed	Total	7.934	9.864	3.107	1.981	1.232	22.886	24.118
	Ave/probe	1.322	1.644	0.518	0.330	0.205	3.814	4.020
	Est./Sq.Ha	1692.587	2104.320	662.827	422.613	262.827	4882.347	5145.173
Fall 2000								
Limed	Total	15.076	5.121	1.530	3.306	1.362	25.033	26.395
	Ave/probe	2.513	0.854	0.255	0.551	0.227	4.172	4.399
	Est./Sq.Ha	3216.213	1092.480	326.400	705.280	290.560	5340.373	5630.933
Unlimed	Total	10.913	11.599	3.942	3.179	0.855	29.633	30.488
	Ave/probe	1.819	1.933	0.657	0.530	0.143	4.939	5.081
	Est./Sq.Ha	13968.640	14846.720	5045.760	4069.120	1094.400	37930.240	39024.640

Table 9C-4: Spring 1999

Table C-4 Fresh gram weights of non-mycorrhizal roots isolated at various soil depths in a Sessile oak forest in Merzalben, in Rheinland-Pfalz, in Spring 1999

Horizon 0-10cm	>5 mm	>1 mm	<1 mm	<< 1 mm	Total	Subtotals
Limed						
1ka 0-10	0.000	5.784	0.000	2.605	8.389	8.389
2ka 0-10 *	0.000	0.000	0.000	0.000	0.000	0.000
3ka 0-10 *	0.000	0.000	0.000	0.000	0.000	0.000
4ka 0-10	0.954	2.164	2.223	1.704	7.045	7.045
5ka 0-10	0.520	1.336	0.781	0.165	2.802	2.802
Subtotals	**1.474**	**9.234**	**3.004**	**4.474**	**18.236**	**18.236**
Unlimed						
1na 0-10	0.000	2.050	0.000	0.533	2.583	2.583
2na 0-10 *	0.000	0.000	0.000	0.000	0.000	0.000
3na 0-10 *	0.000	0.000	0.000	0.000	0.000	0.000
4na 0-10 *	0.000	0.000	0.000	0.000	0.000	0.000
5na 0-10 *	0.000	0.000	0.000	0.000	0.000	0.000
Subtotals	**0.000**	**2.050**	**0.000**	**0.533**	**2.583**	**2.583**
Horizon 30-40 cm						
Limed						
1ka 30-40	0.000	4.036	0.000	0.000	4.036	4.036
2ka 30-40	0.000	0.917	0.000	0.268	1.185	1.185
3ka 30-40	0.000	3.022	0.000	0.000	3.022	3.022
4ka 30-40	1.579	0.996	1.143	0.045	3.763	3.762
5ka 30-40	8.656	1.373	0.400	0.054	10.483	10.483
Subtotals	**10.235**	**10.344**	**1.543**	**0.367**	**22.489**	**22.488**
Unlimed						
1na 30-40	0.000	3.008	0.000	0.000	3.008	3.008
2na 30-40	0.000	1.913	0.000	0.164	2.077	2.077
3na 30-40	0.000	2.667	0.173	0.000	2.840	2.840
4na 30-40	7.629	2.457	2.992	0.074	13.152	13.152
5na 30-40	8.679	1.203	0.561	0.021	10.464	10.464
Subtotals	**16.308**	**11.248**	**3.726**	**0.259**	**31.541**	**31.541**
Horizon 50-60cm						
Limed						
1ka 50-60	0.000	2.940	0.000	0.000	2.940	2.940
2ka 50-60	6.373	2.083	0.216	0.120	8.792	8.792
3ka 50-60	1.893	0.284	0.614	0.000	2.791	2.791
4ka 50-60	3.252	0.355	0.258	0.015	3.880	3.880
5ka 50-60	2.301	2.408	0.580	0.032	5.321	5.321
Subtotals	**13.819**	**8.070**	**1.668**	**0.167**	**23.724**	**23.724**
Unlimed						
1na 50-60	0.000	1.806	0.000	0.000	1.806	1.806
2na 50-60	13.000	0.950	0.397	0.003	14.350	14.350
3na 50-60	0.000	0.719	0.439	0.003	1.161	1.161
4na 50-60	8.857	1.692	0.664	0.130	11.343	11.343
5na 50-60	0.000	0.306	0.053	0.000	0.359	0.359
Subtotals	**21.857**	**5.473**	**1.553**	**0.136**	**29.019**	**29.019**

Table 9C-5: Fall 1999

Table C-5 . Fresh gram weight of non-mycorrhizal roots isolated at various soil depths in a Sessile oak forest in Merzablen, in Rheinland-Pfalz, in Fall 1999

	Root Diameter						
Horizon 0-10 cm	>5 mm	>1 mm	<1 mm	<< 1 mm	Total		Subtotals
Limed							
6ka0-10	0.000	0.574	0.281	0.000	0.855		0.855
7ka0-10	4.145	1.140	1.128	0.090	6.503		6.503
8ka0-10	0.000	0.772	0.412	0.174	1.358		1.358
10ka0-10	0.000	0.627	0.497	0.000	1.124		1.124
x							
x							
Subtotals	**4.145**	**3.113**	**2.318**	**0.264**	**9.840**		**9.840**
Unlimed							
6na0-10	0.000	2.296	1.198	0.000	3.494		3.494
7na0-10	0.340	1.860	1.505	0.134	3.839		3.839
8na0-10	0.000	0.569	0.432	0.108	1.109		1.109
10na0-10	0.541	0.537	0.567	0.470	2.115		2.115
x							
x							
Subtotals	**0.881**	**5.262**	**3.702**	**0.712**	**10.557**		**10.557**
Horizon 30-40 cm							
Limed							
6ka30-40	2.404	0.85	1.149	0.000	4.403		4.403
7ka30-40	0.000	0.937	1.198	0.000	2.135		2.135
8ka30-40	3.157	0.586	0.736	0.076	4.555		4.555
10ka 30-40	0.000	0.282	0.060	0.016	0.358		0.036
x							
x							
Subtotals	**5.561**	**2.655**	**3.143**	**0.092**	**11.451**		**11.129**
Unlimed							
6na30-40	2.357	0.000	1.896	0.000	4.253		4.253
7na30-40	1.355	1.220	0.563	0.000	3.138		3.138
8na30-40	0.000	1.089	0.585	0.041	1.715		1.715
10na30-40	1.739	1.575	0.544	0.065	3.923		3.923
x							
x							
x							
Subtotals	**5.451**	**3.884**	**3.588**	**0.106**	**13.029**		**13.029**
Horizon 50-60 cm							
Limed							
6ka50-60	0.000	0.000	0.000	0.000	0.000		0.000
7ka50-60	4.416	5.000	0.825	0.127	10.368		10.368
8ka50-60	19.468	0.152	0.104	0.000	19.724		19.724
10ka50-60	0.000	0.025	0.054	0.010	0.089		0.009
x							
x							
Subtotals	**23.884**	**5.177**	**0.983**	**0.137**	**30.181**		**30.101**
Unlimed							
6na'50-60	21.900	3.982	5.452	0.000	31.334		
7na50-60	9.477	3.504	1.804	0.028	14.813		
8na50-60	0.000	1.173	0.284	0.115	1.572		
10na50-60	2.361	1.026	0.802	0.026	4.215		
x							
x							
Subtotals	**33.738**	**9.685**	**8.342**	**0.169**	**51.934**		

Table C-6 Fresh gram weights of non-mycorrhizal roots isolated at various soil depths in a Sessile oak forest in Merzalben, in Rheinland-Pfalz, in Spring 2000							
Horizon 0-10 cm	>5 mm	>1 mm	<1 mm	<< 1 mm	Sums		
Limed							
100k0-10	0.000	1.598	0.606	0.000	2.204		2.204
200k0-10	0.000	1.358	1.575	1.630	4.563		4.563
300k0-10	0.460	0.704	0.603	0.227	1.994		1.994
400k0-10e	0.000	0.000	0.580	1.611	2.191		2.191
500k0-10	0.000	0.432	0.882	4.177	5.491		5.491
600k0-10	7.598	0.721	0.177	0.037	8.533		8.533
Subtotals	**8.058**	**4.813**	**4.423**	**7.682**	**24.976**		**24.976**
Unlimed							
100n0-10	0.000	1.277	1.431	0.909	3.617		3.617
200n0-10	0.000	0.874	2.121	2.788	5.783		5.783
300n0-10	2.167	0.721	0.893	0.654	4.435		4.435
400n0-10	0.000	1.255	1.110	1.341	3.706		3.706
500n0-10	0.426	0.000	1.166	3.790	5.382		5.382
600n0-10	0.000	0.000	0.000	0.000	0.000		0.000
Subtotals	**2.593**	**4.127**	**6.721**	**9.482**	**22.923**		**22.923**
Horizon 30-40 cm							
Limed							
100k30-40	4.402	1.442	1.832	0.338	8.014		8.014
200k30-40	10.385	1.960	0.867	0.287	13.499		13.499
300k30-40	3.043	1.537	0.757	0.318	5.655		5.655
400k30-40	13.096	2.163	1.310	0.752	17.321		17.321
500k30-40	0.000	0.852	0.310	0.197	1.359		1.359
600k30-40	2.428	0.086	0.720	1.710	4.944		4.944
Subtotals	**33.354**	**8.040**	**5.796**	**3.602**	**50.792**		**50.792**
Unlimed							
100n30-40	6.966	3.287	3.949	0.465	14.667		14.667
200n30-40	0.000	1.297	0.256	0.248	1.801		1.801
300n30-40	16.072	2.081	0.598	2.434	21.185		21.185
400n30-40	3.922	3.628	1.665	2.138	11.353		11.353
500n30-40	2.479	0.415	0.257	0.188	3.339		3.339
600n30-40	20.390	3.343	0.793	1.323	25.849		25.849
Subtotals	**49.829**	**14.051**	**7.518**	**6.796**	**78.194**		**78.194**
Horizon 50-60 cm							
Limed							
100k50-60	2.189	1.803	2.043	1.094	7.129		7.129
200k50-60	0.000	1.876	1.084	0.201	3.161		3.161
300k50-60	0.000	1.147	0.317	0.132	1.596		1.596
400k50-60	6.784	3.946	0.559	0.237	11.526		11.526
500k50-60	12.157	1.602	0.671	0.081	14.511		14.511
600k50-60	0.000	1.412	0.673	0.550	2.635		26.350
Subtotals	**21.130**	**11.786**	**5.347**	**2.295**	**40.558**		**64.273**
Horizon 50-60 cm	**>5 mm**	**>1 mm**	**<1 mm**	**<< 1 mm**	**Sums**		
Unlimed							
100n50-60	1.501	1.406	0.487	0.316	3.710		3.710
200n50-60	0.771	1.091	1.657	0.666	4.185		4.185
300n50-60	1.984	4.952	0.266	0.133	7.335		7.335
400n50-60	1.374	1.688	0.423	0.341	3.826		3.826
500n50-60	2.304	0.727	0.274	0.525	3.830		3.830
600n50-60	0.000	0.000	0.000	0.000	0.000		0.000
Subtotals	**7.934**	**9.864**	**3.107**	**1.981**	**22.886**		**22.886**

Table 9C-7: Fall 2000

Table C-7 . Fresh gram weight of non-mycorrhizal roots isolated at various soil depths in a Sessile oak forest in Merzablen, in Rheinland-Pfalz, in Fall 2000

	Root Diameter					
Horizon 0-10 cm	**>5 mm**	**>1 mm**	**<1 mm**	**<< 1 mm**	**Total**	**Subtotals**
Limed						
800k0-10	4.536	1.950	1.233	3.122	10.841	10.841
900k0-10	1.433	2.266	1.950	5.655	11.304	11.304
1000k0-10	0.000	0.000	0.000	0.000	0.000	0.000
1100kb0	0.557	0.425	1.887	4.944	7.813	7.813
1200k0-10	0.000	1.294	0.692	3.376	5.362	5.362
1400k0-10	4.597	1.051	1.092	6.501	13.241	13.241
Subtotals	**11.123**	**6.956**	**6.854**	**23.598**	**48.561**	**48.561**
Unlimed						
700n0-10	0.231	0.452	1.430	6.315	8.428	8.428
800n0-10	0.315	2.331	0.861	2.462	5.969	5.969
900n0-10	0.745	1.141	0.994	2.396	5.276	5.276
1100n0-10	0.112	1.113	0.920	0.685	2.830	2.830
1200n0-10	0.000	0.118	0.176	0.221	0.515	0.515
1600k0-10	2.141	2.668	1.933	6.094	12.836	12.836
Subtotals	**3.544**	**7.823**	**6.314**	**18.173**	**35.854**	**35.854**
Horizon 30-40 cm						
Limed						
800k30-40	0.000	0.942	0.525	0.086	1.553	1.553
900k30-40	6.483	1.957	0.266	2.300	11.006	11.006
1000k30	14.865	1.993	0.333	1.520	18.711	18.711
1100kb30	0.000	2.143	0.622	1.267	4.032	4.032
1200kc30	17.430	1.648	0.300	1.391	20.769	20.769
1400kb30	0.000	2.653	0.232	1.043	3.928	3.928
Subtotals	**38.778**	**11.336**	**2.278**	**7.607**	**59.999**	**59.999**
Unlimed						
700n30-40	14.843	2.030	1.125	0.509	18.507	18.507
800n30-40	5.840	1.554	0.766	0.297	8.457	8.457
900n30-40	0.000	3.106	0.598	0.355	4.059	4.059
1000n30	1.046	0.554	0.121	0.487	2.208	2.208
1100n30	0.000	0.066	0.170	0.535	0.771	0.771
1200n30	0.000	2.097	0.808	0.768	3.673	3.673
1600nb30	0.000	3.801	0.936	0.495	5.232	5.232
Subtotals	**21.729**	**13.208**	**4.524**	**3.446**	**42.907**	**42.907**
Horizon 50-60 cm						
Limed						
800k50-60	0.000	0.000	0.000	0.000	0.000	0.000
900k50-60	2.077	0.959	0.449	0.692	4.177	4.177
1000k50	1.282	0.283	0.233	0.289	2.087	2.087
1100kb50	11.717	1.667	0.136	1.280	14.800	14.800
1200kc50	0.000	0.508	0.107	0.717	1.332	1.332
1400kb50	0.000	1.704	0.605	0.328	2.637	2.637
Subtotals	**15.076**	**5.121**	**1.530**	**3.306**	**25.033**	**25.033**
700n50-60	1.052	0.436	0.399	0.888	2.775	2.775
800n50-60	3.386	3.396	0.540	0.001	7.323	7.323
900n50-60	0.000	2.413	0.927	0.341	3.681	3.681
1100n50	0.000	1.416	0.319	0.372	2.107	2.107
1200n50	1.510	1.416	0.653	0.398	3.977	3.977
1600nb50	4.965	2.522	1.104	1.179	9.770	9.770
Subtotals	**10.913**	**11.599**	**3.942**	**3.179**	**29.633**	**29.633**

Appendix 9D: Statistical Analysis Formulas

9D-1A: Calculating Significant Differences: Student T test

Data preparation for computed student t test :

Step 1: Sum of Initial data sets
$\Sigma_{1}i = \Sigma (X_{1}i)$ = the initial sum of the initial values for set 1
$\Sigma_{2}i = \Sigma (X_{2}i)$ = the initial sum of the initial values for set 2

Step 2: Mean
$\bar{x}_1 = \Sigma_{1}i / n_1$ = mean value of the sum of initial values divided by the number of values for set 1
$\bar{x}_2 = \Sigma_{2}i / n_2$ = mean value of the sum of initial values divided by the number of values for set 2

Step 3: Devation from the Mean
$(X_{1}i - \bar{x}_1)$ = the difference between each individual value and the mean for set 1
$(X_{2}i - \bar{x}_2)$ = the difference between each individual value and the mean for set 2

Step 4: Squares of the deviations
$(X_{1}i - \bar{x})^2$ = the square of the difference for each value in set 1
$(X_{2}i - \bar{x})^2$ = the square of the difference for each value in set 2

Step 5: Sum of squares
$S_1 = \Sigma\ (X_{1}i - \bar{x})^2$ = sum of the squares for all the values in set 1
$S_2 = \Sigma\ (X_{2}i - \bar{x})^2$ = sum of the squares for all the values in set 2

Step 6 : Variance from the mean (Standard Deviation)
$S_1^2 = S_1 / (n-1)$ = sum of squares for set 1 divided by the total number of samples minus one for set 1
$S_2^2 = S_2 / (n-1)$ = sum of squares for set 2 divided by the total number of samples minus one for set 2

Step 7: Comparison of the two data sets

$$S\,\bar{x}_1 - \bar{x}_2 = \sqrt{(S_1^2 + S_2^2) / n}$$

Step 8: Computed student t test

$$t = (\bar{x}_1 - \bar{x}_2) / (S\,\bar{x}_1 - \bar{x}_2)$$

Step 9: Determining Factor

$$dF = 2\,(n-1)$$

Step 10: Comparison to table values for determining Significant difference
Using Table for t values from Steel and Torrie (1960, p46) with the determining factor
If the computed t > tabular $t_{0.05}$,we are 95% confident of a significant difference
If the computed t > tabular $t_{0.01}$, we are 99% certain of a highly significant difference
If the computed t > tabular $t_{0.001}$. we are 99.9% sure the samples are definitively different.

Appendix 9D: Statistical Analysis Formulas

9D-1B: Calculating Significant Differences: Student T Test - Examples

Example: Percentage Moisture of Limed and Unlimed Soil at 50-60 cm Depth for Spring 1999
Original Data Set 1= % Moisture for Unlimed Soil

Data (X_{1i})	Step 1 $\Sigma_{1i}=\Sigma(X_{1i})$	Step 2 $\bar{x}=\Sigma_{1i}/n_1$	Step 3 $(X_{1i}-\bar{x})$	Step 4 $(X_{1i}-\bar{x})^2$	Step 5 $S_1=\Sigma(X_{1i}-\bar{x})^2$	Step 6 $S_1^2=S_1/(n-1)$
25	Σ_{1i}=114	$\bar{x}$=114/5	25-22.8= 2.2	$(2.2)^2$= 4.8400	S_1 =48.7604	S_1^2 =48.7604 / (5-1)
27		$\bar{x}$=22.8	27-22.8= 4.2	$(4.2)^2$= 17.6400		S_1^2 = 12.1901
23			23-22.8= 0.2	$(0.2)^2$= 0.0004		
21			21-22.8= 1.8	$(1.8)^2$= 3.2400		
18			18-22.8=-4.8	$(-4.8)^2$=23.0400		
114				48.7604		

Original Data Set 2= % Moisture for Limed Soil

Data (X_{1i})	Step 1 $\Sigma_{1i}=\Sigma(X_{1i})$	Step 2 $\bar{x}=\Sigma_{1i}/n_1$	Step 3 $(X_{1i}-\bar{x})$	Step 4 $(X_{1i}-\bar{x})^2$	Step 5 $S_1=\Sigma(X_{1i}-\bar{x})^2$	Step 6 $S_1^2=S_1/(n-1)$
25	Σ_{1i}=144	$\bar{x}$=144/5	25-28.8= 3.8	$(3.8)^2$ = 14.44	S_1 =70.8	S_1^2 =70.8 / (5-1)
34		$\bar{x}$=28.8	34-28.8= 5.2	$(5.2)^2$ = 27.04		S_1^2 =17.7
31			31-28.8= 2.2	$(2.2)^2$ = 4.84		
30			30-28.8= 1.2	$(1.2)^2$ = 1.44		
24			24-28.8=-4.8	$(-4.8)^2$ =23.04		
144				70.80		

Step 7: Comparison of the two data sets

$S\,\bar{x}_1 - \bar{x}_2 = \sqrt{(S_1^2 + S_2^2)/n} = \sqrt{(12.1901 + 17.7)/5} = \sqrt{29.8901/5} = \sqrt{5.97802} = 2.445$

Step 8: Computed student t test

$t = (\bar{x}_1 - \bar{x}_2) / (S\,\bar{x}_1 - \bar{x}_2) = (22.8 - 28.8) / 2.445 = 6 / 2.445 = 2.454$

Step 9: Determining Factor (Normally a minimum of n >10 values are needed.)

$dF = 2\,(n-1) = 2\,(5-1) = 8$

Step 10: Comparison to table values for determining Significant difference
Using Table for t values from Steel and Torrie (1960, p46)
If the computed t > tabular $t_{0.05}$,we are 95% confident of a significant difference
If the computed t > tabular $t_{0.01}$, we are 99% certain of a highly significant difference
If the computed t > tabular $t_{0.001}$. we are 99.9% sure the samples are definitively different.

Results:
For dF = 8 : tabular $t_{0.05}$ = 2.306, tabular $t_{0.01}$ = 3.355, tabular $t_{0.001}$ = 5.041
Computed t = 2.454 > tabular $t_{0.05}$ = 2.306 Therefore there is a significant difference, but since
Computed t = 2.454 < tabular $t_{0.01}$ = 3.355 The difference in not highly significant.

Appendix 9D: Statistical Analysis Formulas

9D-2: Standard Deviation, Average, Mean, Mode

9D-2A: Standard Deviation

$$\text{STDEV} = \sqrt{\frac{n \sum x^2 - (\sum x)^2}{n(n-1)}}$$

The standard deviation is a measure of how widely values are dispersed from the average value (the mean). If the data represents an entire population then the STDEVP should be calculated. Using the computer function mode the command will encompass the data sets in a column or a row using the command STEDEV (A1: A15) for 15 cells in a column or STDEV (A1:E15) for 15 cells in a row. The STDEV is calculated using the nonbiased mode of n-1. (n-1 would be 14 for the example above.)

9D-2B: Average, Mean, Mode

1. Average = $\bar{x} = \Sigma x / n$ = sum of individual values divided by the number of values used

2. Mean = $\Sigma(\ldots x \cdot n_3 + y \cdot n_2 + z \cdot n_1 \ldots) / (n_1 + n_2 + n_3) = \Sigma x / n = \bar{x}$
Mean = sum of repeated individual values (x,y,z ...) times the number of times each is repeated (n_1, n_2, n_3 ...) divided by the total number of repeats. (Expanded averaging)

3. Mode = Individual value that is most often repeated. (Frequency of occurance or Trend)

Average, Mean, Mode Examples:
From research data: % Moisture for Unlimed and Limed Soil at 30-40 cm depth for Spring 1999

Example 1: Unlimed soil
Original data values = 22%, 22%, 13%, 13%, 22%, 7%
1. Average = $\bar{x} = \Sigma x / n$ = (22+22+13+13+22+7) / 6 = 99 / 6 = 16.5 %
2. Mean = $\Sigma(\ldots x \cdot n_3 + y \cdot n_2 + z \cdot n_1 \ldots) / (n_1 + n_2 + n_3)$ = Σ [(22x3) + (13x2) + (7x1)] / 6 = 16.5%
3. Mode = 22%

Example 2: Limed soil
Original data values = 15%, 18%, 21%, 18%, 16%, 9%
1. Average = $\bar{x} = \Sigma x / n$ = (15+18+21+18+16+9) / 6 = 97 / 6 =16.1 %
2. Mean = $\Sigma(\ldots x \cdot n_3 + y \cdot n_2 + z \cdot n_1 \ldots) / (n_1 + n_2 + n_3)$
= Σ[(18x2) + (15x1) + (21x1) + (16x1) + (9x1)] / 6 = 16.1%
3. Mode = 18%

Appendix 9D: Statistical Analysis Formulas

9D-3: Exponential Growth, Carrying Capacity, Successive Populations

9D-3A: Exponential Growth Calculations

Step 1: Calculating Rate (r)
r = log of the number on day t (ln Nt) minus the log of the initial number (ln No) divided by time (t)
r = (ln Nt- ln No) / t

Example : Calculating general growth rate over time :If the initial lemna sample contained 3 leaves, and 3 days later the lemna sample contained 14 leaves then the growth rate will be : r = 1.5554 leaves per day.
r = (log 14 - log 3) / 3 days = (ln 2.639 - ln 1.086) / 3 = lnv (ln 1.5404) / 3 = 4.6664565 / 3 = 1.5554
r = 1.5554 leaves per day

Step 2: Maximum Rate Value (rm)
Calculate the r value for each day to find the maximum rate (rm) using the formula above.
Example: If r = 1.5 on day one, r = 1.5554 on day two, and r = 1.4 on day three, then rm = 1.5554

Step 3: Predicting exponential growth (ΔN / Δ t)
ΔN / Δ t = No (rm . t)
Example : If the initial number is No = 3, the rate is rm= 1.5554 and time duration is t=5 days :
ΔN / Δ t = 3 (1.5554 x5) = 3 (7.777) = 23.331
ΔN / Δ t = 23.331 leaves will be present on day 5 if maximum growth rate is maintained

9D-3B: Carrying Capacity Calculations

K= maximum number of individuals possible in a given environment.
K= number derived (Nt) from graph or extrapolated data (best guess) relative to initial population (No)

rm = (log Nt - log No) / t ∴ **t = (log Nt - log No) / rm**

Example: If the predicted carrying capacity (K) is 500 (Nt = 500) and initially there are only 3 individuals (No = 3) and the maximum growt rate is estimated to be 1.5554 (rm= 1.5554), then the minimum number of days needed to reach carrying capacity will be (t = 105.59 days).
t = (log Nt - log No) / rm = (ln 500 - ln3) / 1.5554 = (ln 6.2 - ln 1.0986) / 1.5554 = ln 5.1014 / 1.5554
t = inv (ln 5.1014) / 1.5554 = 164. 25 / 1.5554 = 105.59
t = 105.59 days to reach carrying capacity at maximum growth rate

9D-3C: Calculating Successive populations (# in Next Generation = Nt)

rm = (log Nt - log No) / t	Original formula
∴ rm · t = (log Nt -log No)	Divide both sides by t
∴ (rm · t) + log No = log Nt	Add log No to both sides
∴ log Nt = (rm · t) + log No	Invert formula
∴ Nt = INV log Nt	Cancel log function

Example: If the initial population is 50 (no = 50) and the next generation (t=2) is predicted to reproduce at a maximum rate of 0.4 (rm = 0.4), then there will be Nt = 111.27 individuals in the next generation.
Log Nt = (rm· t) + log No = (0.4 x 2) + log 50 = (0.8) + 3.912 = 4.712
Nt = INV log Nt = INV 4.712 = 111.27
Nt = 111.27 individuals will probably be produced in the next generation

Appendix 9D: Statistical Analysis Formulas

9D-4: Environmental Resistance

R = (K-N) / K

As long as K>N the population will survive but as the population number (N) approaches carrying capacity (K), environmental limitations [R] will limit survivability until Zero Population growth (ZPG) is acheived where K=N. If the population should continue to increase to exceed the carrying capacity (N>K), the death rate will exceed the birth rate.

Example: If the mycorrhiza *Byssocorticium atrovirens* is sensitive to solubilized aluminum at low concentrations, then its population (number of tips) will be limited with respect to the level of nutrients (or conversely) toxic elements in the soil. In a given (ficticious) rhizosphere with the same pH and same Calcium concentration, 6 soil samples are examined and the maximum number of tips found is 35 (but 4 of these tips are unhealthy looking) with the other samples having : 15, 12, 12, 9 and 5 tips. We could assume that 35-4 = 31 tips may be the carrying capacity of the sample.

If 5 tips are present in a similar environment then R = (K-N) / K = (31-5) / 31= 0.8387
% Survival chance = R x 100 = 0.8387 x 100 = 83.87 %

Similarily if 15 tips are present then R = (31-15) / 31 = 0.5161 and % survival chances are 51.61%.
If 35 tips are present then R = (31-35) / 31 = - 0.129 and % survival chances are -12.9% (death phase)

The carrying capacity (K) of an environment will decline if the nutrients are leached from the soil or toxic factors are introduced. If either, or both, of these events occur, an existing population will suffer population dieback and reduced numbers relative to control environments.

Selection Pressures

K Selection

Stable environments tend to promote preferential growth over a long period of time of certain successful species to the detriment of less suitable species. As a result, the biodiversity is reduced. In K selection, despite the reduced diversity, the population size of each of the successful species is generally large and self-maintaining. The rate of growth tends to be slower possibly due to maximized resource use as the population approaches carrying capacity. K strategists are characterized as producing few, fairly large offspring with a great deal of time and energy invested to ensure healthy survival to reproductive age with the end result of being capable of maintaining their populations size near the habitat's carrying capacity (Miller, 1992). The generally stable, or very slowly changing, environmental factors help to maintain the established community. Allelic variations within existing populations may contribute to species persistance in slowly altering ecosystems. Forests are typically stable ecosystems abundantly populated with a limited number of species but they can be altered.

r Selection

Unstable or suddenly altered environments will contribute to r selection. Existing populations, stressed by unfavorable changes may suffer dieback. Reduced competition and changes in niche resources can then allow normally marginal populations to become opportunistic. In the transitional phase, temporary increases in biodiversity but overall reductions in population numbers are a sign of a stressed or altered environment. The population sizes of the new complement of pioneer species is then determined by their individual variable growth rates, which can be influenced by a mydriad of factors such as; moisture, pH, nutrient leaching, toxin accumulations, competition, predation, waste accumulation, disease, sunlight, wind, space, and host species. Interacting, opportunistic species often suddenly appear and dissappear with great diversity but not necessarily great numbers unless a particular species is more suitably adapted to survive the environmental change and can outcompete the others. The reproductive mode of r-strategists is generally characterized by early appearance, and large number of usually small, short-lived offspring which are competitively inferior and vunerable, but some survive long enough to reproduce (Miller, 1992).

Eventually, if the environment is maintained in this new altered state over a long time period, (stablizes) there may be a shift back to K selection but with an entirely new relative complement of organisms sharing the new eco-community (succession).

References

Grossman SI, Turner JE. 1974. *Mathematics for the Biological Sciences*. Macmillan Pub. Co., New York. P. 367-395.

Miller GT, 1992. *An Introduction to Environmental Science: Living in the Environment.* Wadsworth Pub. Co., Belmont, CA., p151.

Appendix 10: Bound Mineral Analysis

Purpose:
1. To demonstrate the quantitative amounts of Aluminum, Calcium, and several other physiologically important minerals in mycorrhizal roots.
2. To determine if the fluorescence data was correlated to actual mineral content of the mycorrhizal roots.

Appendix 10A Tables 1-6: Bound Mineral Analysis of fine mycorrhizal oak roots from unlimed (N) and limed (K) soil at 0-10, 30-40 and 50-60 cm depths.

Table 10A-1: Analysis of bound minerals present in unlimed fine mycorrhizal oak roots at 0-10 cm depth.

Bound		Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn	Cd	Pb
Content		**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**	**mg/kg**
Spring 1999	LNR												
1N 0-10	8984	4540	12520	2330	1520	661	2500	361	1023	1472	181	1.070	55.30
2N 0-10	8985	6180	2810	849	1140	125	5320	646	676	1083	60	0.580	70.70
3N 0-10	8986	6410	2820	943	1260	105	4600	810	747	984	67	0.580	94.10
4N 0-10	8987	5150	1980	532	1010	105	8810	503	1074	1171	65	0.390	120.00
5N 0-10	8988	4310	1930	826	1590	156	3520	271	711	1104	49	0.470	82.20
6NA 0-10	8989	888	2690	970	2220	111	314	460	599	1044	30	0.590	28.70
Average		**4580**	**4125**	**1075**	**1457**	**211**	**4177**	**509**	**805**	**1143**	**75**	**0.613**	**75.17**
Stand. Dev.		1997	4132	634	434	222	2868	195	196	173	54	0.237	31.60
Fall 1999													
7N 0-10	9002	4350	2910	840	1150	152	3340	337	737	1051	101	0.510	63.00
8N 0-10	9003	2250	4770	530	313	79	1640	163	527	846	225	0.640	32.90
9N 0-10	9004	5620	907	499	1200	90	3500	189	633	1197	46	0.320	74.00
10N 0-10	9005	9090	2870	692	1420	288	5220	363	1260	1219	136	0.470	102.50
11N 0-10	9006	8450	3240	775	1390	219	4430	554	833	1152	77	0.620	96.60
12N 0-10	9007	7650	1350	651	1500	143	4060	196	763	1067	42	0.330	88.20
Average		**6235**	**2675**	**665**	**1162**	**162**	**3698**	**300**	**792**	**1089**	**105**	**0.482**	**76.20**
Stand. Dev.		2641	1392	134	437	80	1215	150	253	137	69	0.137	25.71
Spring 2000													
100N 0-10	9059	7810	3520	947	1760	169	3090	929	923	1256	102	0.930	78.50
200N 0-10	9060	5330	1870	777	1930	353	3290	264	1042	1396	74	1.140	144.60
300N 0-10	9061	2350	4040	939	1230	250	1150	449	767	1159	206	0.840	97.30
400N 0-10	9062	6070	2350	492	875	161	2900	458	858	1216	136	0.700	102.00
500N 0-10	9063	7330	3670	851	1170	223	6200	147	1055	1467	98	0.470	165.50
600N 0-10	9064	9660	4210	959	1610	576	4540	726	1203	1746	75	0.400	116.90
Average		**6425**	**3277**	**828**	**1429**	**289**	**3528**	**496**	**975**	**1373**	**115**	**0.747**	**117.47**
Stand. Dev.		2495	949	179	402	157	1701	290	157	216	50	0.281	32.27
Fall 2000													
700N 0-10	9077	10250	13420	2430	2050	415	7670	911	907	2138	336	1.230	112.50
800N 0-10	9078	15300	5620	1630	2290	299	7310	633	935	1690	161	0.350	111.10
900N 0-10	9079	11010	2490	803	1790	243	6520	232	928	1652	98	0.250	145.40
1100N 0-10	9080	10010	2910	974	3500	400	5690	544	1118	1437	124	0.620	126.20
1200N 0-10	9081	10650	2300	695	1290	185	4420	189	1102	1553	78	0.280	100.30
1400N 0-10	9082	2690	5070	914	1160	351	1740	207	705	1467	108	0.810	161.50
1600N 0-10	9084	5610	4400	1260	2920	609	2820	644	1085	1567	129	1.100	85.80
Average		**9360**	**5173**	**1244**	**2143**	**357**	**5167**	**480**	**969**	**1643**	**148**	**0.663**	**120.40**
Stand. Dev.		4071	3860	610	846	138	2265	277	147	236	87	0.398	26.13

Wurzelextrakte UKS Merzalben, LUFA Speyer, den 02.04.01: LNR=Laufennummer (Run number)

Appendix 10A Tables 1-6: Bound Mineral Analysis of fine mycorrhizal oak roots from unlimed (N) and limed (K) soil at 0-10, 30-40 and 50-60 cm depths.

Table 10A-2: Analysis of bound minerals present in limed fine mycorrhizal oak roots at 0-10 cm depth.

Bound		Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn	Cd	Pb
Content		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Spring 1999	LNR												
1K 0-10	8948	2930	17890	2760	1000	514	2410	471	820	1470	421	0.710	73.00
2K 0-10	8949	3980	5910	2200	857	126	6610	808	580	1089	49	0.560	79.70
3K 0-10	8950	5120	8890	3450	1180	188	6420	675	542	1101	57	0.370	66.20
4K 0-10	8951	6300	7890	2660	1560	257	4290	928	746	1422	133	1.130	109.00
5K 0-10	8952	2370	9390	1820	361	105	1300	252	421	845	260	0.660	39.80
6K 0-10	8953	6910	8370	1710	1510	186	4090	162	773	1160	638	1.070	74.60
Average		**4602**	**9723**	**2433**	**1078**	**229**	**4187**	**549**	**647**	**1181**	**260**	**0.750**	**73.72**
Stand.Dev.		1824	4177	655	447	149	2115	307	156	232	233	0.296	22.31
Fall 1999													
7K 0-10	8966	2670	7560	2730	3110	509	1560	222	618	1420	282	1.030	50.50
8K 0-10	8967	8010	5590	1930	1810	204	5250	466	713	1377	115	0.490	69.70
9K 0-10	8968	7680	2620	1280	1960	154	5390	261	760	1233	76	0.940	107.80
11K 0-10	8970	7370	4930	2220	1620	127	7110	1450	659	1011	55	0.570	73.40
12K 0-10	8971	5690	5820	2690	2380	246	2870	709	647	1177	74	0.630	55.60
Average		**6284**	**5304**	**2170**	**2176**	**248**	**4436**	**622**	**679**	**1244**	**120**	**0.732**	**71.40**
Stand. Dev.		2209	1788	599	592	153	2205	502	57	164	93	0.238	22.46
Spring 2000													
100K 0-10	9020	6180	8890	2410	1600	281	2980	571	721	1045	193	0.840	68.60
200K 0-10	9021	8140	8800	1560	1690	296	6350	1070	968	1325	396	1.330	126.00
300K 0-10	9022	10110	3040	1840	2600	316	5530	431	826	1116	114	2.020	87.00
400K 0-10	9023	9870	7660	1690	1350	382	4180	363	791	1142	341	1.110	100.30
500K 0-10	9024	12980	3910	1810	2040	204	8460	563	870	1094	91	0.590	97.00
600K 0-10	9025	11990	6180	2090	2000	254	6730	742	774	1240	90	0.530	118.70
Average		**9878**	**6413**	**1900**	**1880**	**289**	**5705**	**623**	**825**	**1160**	**204**	**1.070**	**99.60**
Stand. Dev.		2483	2493	306	437	60	1941	255	86	103	134	0.556	20.92
Fall 2000													
800K 0-10	9038	14500	5300	1980	2770	320	8080	347	887	1426	205	0.690	95.70
900K 0-10	9039	12030	8180	1920	1900	267	6500	433	842	1529	137	0.620	104.90
1000K 0-10	9040	7850	9550	1700	2230	627	5520	1720	1136	1463	126	1.000	127.90
1100K 0-10	9041	9900	3860	1480	2880	430	6420	669	973	1323	150	1.720	94.40
1100K 0-10	9042	16600	4110	1700	2800	303	10630	587	983	1222	147	1.000	140.00
1200K 0-10	9043	13880	4040	1510	2700	397	7090	507	808	1095	98	0.930	90.30
1400K 0-10	9044	11030	5050	1800	3610	640	7250	359	949	1413	162	2.150	113.10
Average		**12256**	**5727**	**1727**	**2699**	**426**	**7356**	**660**	**940**	**1353**	**146**	**1.159**	**109.47**
Stand. Dev.		2974	2244	190	538	152	1648	482	109	151	33	0.564	18.66

Appendix 10A Tables 1-6: Bound Mineral Analysis of fine mycorrhizal oak roots from unlimed (N) and limed (K) soil at 0-10, 30-40 and 50-60 cm depths.

Table 10A-3: Analysis of bound minerals present in unlimed fine mycorrhizal oak roots at 30-40 cm depth.

Bound		Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn	Cd	Pb
Content		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Spring 1999	LNR												
1N 30-40	8990	12310	5000	999	1870	308	886	345	919	1152	404	2.700	24.50
2N 30-40	8991	10140	8900	1630	1220	248	1010	417	505	725	220	0.930	21.90
3N 30-40	8992	10340	7840	1110	1180	290	763	596	504	738	278	1.200	19.30
4N 30-40	8993	16230	2320	569	990	102	1550	1100	779	715	182	2.110	10.70
5N 30-40	8994	8100	4820	1060	610	133	647	818	563	732	293	1.930	6.70
6N 30-40	8995	3220	3860	1020	2550	209	1880	122	601	842	86	0.640	26.80
Average		**10057**	**5457**	**1065**	**1403**	**215**	**1123**	**566**	**645**	**817**	**244**	**1.585**	**18.32**
Stand. Dev.		4332	2471	339	695	84	486	351	168	170	108	0.788	7.96
Fall 1999													
7N 30-40	9008	12770	3990	967	1970	287	1600	369	627	933	195	1.810	12.60
8N 30-40	9009	16260	7320	1450	1670	912	1230	406	463	1816	166	0.820	4.40
9N 30-40I	9010	15240	1530	838	2150	106	2630	505	546	658	123	1.850	10.80
10N 30-40	9011	18430	4280	729	1270	138	3100	426	544	681	107	1.180	13.80
11N 30-40	9012	16730	3520	704	1950	144	2360	453	785	769	169	2.110	8.10
12N 30-40	9013	16730	2190	463	1450	83	2610	376	544	735	187	2.050	8.80
Average		**16027**	**3805**	**859**	**1743**	**278**	**2255**	**423**	**585**	**932**	**158**	**1.637**	**9.75**
Stand. Dev.		1900	2024	334	339	318	703	51	111	444	35	0.519	3.40
Spring 2000													
100N 30-40	9065	21270	1360	630	1950	314	2160	863	711	744	130	1.320	11.00
200N 30-40	9066	3230	4190	871	2480	276	1380	295	638	992	182	0.760	66.20
300N 30-40	9067	21400	1820	568	1100	178	1290	351	600	701	122	1.080	31.50
400N 30-40	9068	18000	2710	719	873	185	872	697	696	828	119	1.480	11.70
500N 30-40	9069	17350	697	764	3230	181	1870	262	556	757	61	0.580	7.20
600N 30-40	9070	17610	2640	697	1360	189	1010	524	546	789	115	1.720	7.30
Average		**16477**	**2236**	**708**	**1832**	**221**	**1430**	**499**	**625**	**802**	**122**	**1.157**	**22.48**
Stand. Dev.		6739	1226	105	902	59	497	242	70	103	39	0.435	23.26
Fall 2000													
700N 30-40	9085	15180	4600	1180	2200	311	2110	716	550	894	115	1.280	11.40
800N 30-40	9086	21960	2980	651	1840	244	972	274	578	758	191	1.200	5.50
900N 30-40	9087	20480	2490	717	2210	300	2700	300	585	783	122	1.710	7.50
1100N 30-40	9088	26420	2370	558	1180	225	1960	272	835	972	83	1.350	14.30
1200N 30-40	9089	18400	1930	488	999	151	1180	655	596	757	133	1.200	7.40
1400N 30-40	9090	10220	3300	686	1940	365	6550	53	601	799	180	1.180	43.40
1600N 30-40	9091	17490	3510	957	2870	433	1970	544	625	971	187	1.980	9.50
Average		**18593**	**3026**	**748**	**1891**	**290**	**2492**	**402**	**624**	**848**	**144**	**1.414**	**14.14**
Stand. Dev.		5151	886	241	641	93	1882	241	96	96	42	0.310	13.22

Wurzelextrakte UKS Merzalben, LUFA Speyer, den 02.04.01: LNR=Laufennummer (Run number)

Appendix 10A Tables 1-6: Bound Mineral Analysis of fine mycorrhizal oak roots from unlimed (N) and limed (K) soil at 0-10, 30-40 and 50-60 cm depths.

Table 10A-4: Analysis of bound minerals present in limed fine mycorrhizal oak roots at 30-40 cm depth.

Bound		Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn	Cd	Pb
Content		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
Spring 1999	LNR												
1K 30-40	8954	17920	9750	2420	2100	875	1400	426	958	1380	502	3.790	31.70
2K 30-40	8955	13800	11870	2270	2120	507	1950	529	553	873	598	2.300	16.40
3K 30-40	8956	15200	7180	2140	1420	431	1160	285	676	1760	309	1.290	16.00
4K 30-40	8957	12390	5230	1590	726	139	1350	419	504	948	298	0.740	12.70
5K 30-40	8958	10260	6840	1090	1170	161	501	591	1236	923	192	1.180	8.00
Average		**13914**	**8174**	**1902**	**1507**	**423**	**1272**	**450**	**785**	**1177**	**380**	**1.860**	**16.96**
Stand. Dev.		2889	2626	552	604	300	522	117	307	384	165	1.221	8.90
Fall 1999													
7K 30-40	8972	12010	2790	1740	1690	200	1500	249	606	693	220	1.030	17.00
8K 30-40	8973	16830	2690	1470	1790	174	2760	209	481	688	107	1.030	10.30
9K 30-40	8974	18460	2320	1580	1790	206	4130	276	461	631	137	1.600	16.10
10K 30-40	8975	3050	13310	1790	873	209	1690	437	617	888	325	0.630	34.60
11K 30-40	8976	15970	2750	1700	2270	167	3160	814	525	661	76	0.720	10.10
12K 30-40	8977	16770	3460	1450	1750	215	3850	863	554	789	80	0.940	19.40
Average		**13848**	**4553**	**1622**	**1694**	**195**	**2848**	**475**	**541**	**725**	**158**	**0.992**	**17.92**
Stand. Dev.		5713	4306	143	453	20	1087	293	64	96	98	0.341	8.99
Spring 2000													
100K 30-40	9026	18780	1370	1540	1430	197	1970	325	566	854	109	1.970	18.80
200K 30-40	9027	16910	2980	1290	1730	222	1810	481	624	869	163	1.760	25.00
300K 30-40	9028	21190	2590	1550	1210	165	1340	270	592	746	133	1.410	4.90
400K 30-40	9029	20240	2830	1540	1150	142	1920	998	676	912	83	1.100	27.10
500K 30-40	9030	12880	2100	1360	2700	170	1960	289	407	662	58	1.040	8.20
600K 30-40	9031	20390	1820	1370	1410	334	2630	675	590	843	76	1.630	11.80
Average		**18398**	**2282**	**1442**	**1605**	**205**	**1938**	**506**	**576**	**814**	**104**	**1.485**	**15.97**
Stand. Dev.		3097	626	115	574	69	413	285	91	93	39	0.370	9.10
Fall 2000													
800K 30-40	9045	17600	2980	1160	1880	243	1640	258	476	790	242	2.020	8.40
900K 30-40	9046	17900	3070	1010	1690	222	1680	206	549	790	90	1.700	12.40
1000K 30-40	9047	16490	2130	1140	1180	239	3320	213	594	1101	48	0.730	14.50
1100K 30-40	9048	19660	2880	1240	2110	431	2500	438	628	944	161	2.420	13.10
1100K 30-40	9049	21510	2910	1340	2000	339	4710	160	547	756	69	1.260	12.20
1200K 30-40	9050	17640	1850	1180	2340	309	4370	361	426	666	92	1.290	7.90
1400K 30-40	9051	17090	4920	1430	2690	431	1940	268	635	923	193	1.210	7.70
Average		**18270**	**2963**	**1214**	**1984**	**316**	**2880**	**272**	**551**	**853**	**128**	**1.519**	**10.89**
Stand. Dev.		1731	982	138	480	89	1276	97	78	145	72	0.568	2.81

Wurzelextrakte UKS Merzalben, LUFA Speyer, den 02.04.01: LNR=Laufennummer (Run number)

Appendix 10A Tables 1-6: Bound Mineral Analysis of fine mycorrhizal oak roots from unlimed (N) and limed (K) soil at 0-10, 30-40 and 50-60 cm depths.

Table 10A-5; Analysis of bound minerals present in unlimed fine mycorrhizal oak roots at 50-60 cm depth.

Bound Content		Al mg/kg	Ca mg/kg	Mg mg/kg	K mg/kg	Na mg/kg	Fe mg/kg	Mn mg/kg	P mg/kg	S mg/kg	Zn mg/kg	Cd mg/kg	Pb mg/kg
Spring 1999	LNR												
1N 50-60	8996	14920	8560	1250	1460	349	1080	424	719	1725	360	1.350	15.20
2N 50-60	8997	10210	5580	1120	789	216	1390	543	507	1233	106	0.960	5.40
3N 50-60	8998	12160	5040	816	721	216	1090	466	484	840	134	1.120	5.60
4N 50-60	8999	13390	4860	806	910	176	885	628	621	681	332	1.750	3.60
5N 50-60	9000	13550	3350	515	1170	149	2330	197	468	510	73	0.580	14.00
6N 50-60	9001	15850	2920	699	2430	296	991	111	579	834	115	0.790	8.00
Average		**13347**	**5052**	**868**	**1247**	**234**	**1294**	**395**	**563**	**971**	**187**	**1.092**	**8.63**
Stand. Dev.		2001.6	2003.2	271.72	640.44	75.24	534.61	200.97	96.289	440.39	125.3	0.417	4.84
Fall 1999													
7N 50-60	9014	11800	2840	879	1990	181	1850	291	588	657	163	1.910	7.20
8N 50-60	9015	9370	5700	1250	1517	574	1080	359	363	1015	124	1.080	8.70
9N 50-60	9016	14880	1760	1040	1560	188	2910	412	506	629	160	2.130	13.40
10N 50-60	9017	10980	6120	1240	811	198	761	509	457	646	173	0.900	6.10
12N 50-60	9019	16690	3900	814	2290	184	2930	554	752	678	170	1.940	15.10
Average		**12744**	**4064**	**1045**	**1634**	**265**	**1906**	**425**	**533**	**725**	**158**	**1.592**	**10.10**
Stand. Dev.		2980	1853	201	560	173	1007	107	147	163	20	0.560	3.95
Spring 2000													
100N 50-60	9071	18080	1570	627	3520	130	870	516	558	864	84	0.930	10.40
200N 50-60	9072	14670	1310	458	1560	137	2450	172	571	753	156	1.530	14.60
300N 50-60	9073	9010	570	770	2720	402	3200	170	527	717	125	1.400	18.00
400N 50-60	9074	20500	1190	549	1840	216	767	786	638	741	74	0.910	2.50
500N 50-60	9075	13570	2280	808	1900	217	892	393	626	740	119	1.050	7.10
600N 50-60	9076	21110	514	588	1800	98	2880	334	509	674	65	1.180	12.30
Average		**16157**	**1239**	**633**	**2223**	**200**	**1843**	**395**	**572**	**748**	**104**	**1.167**	**10.82**
Stand. Dev.		4627.6	659.37	133.52	748.16	110.11	1122	233.07	51.887	63.294	35.188	0.254	5.50
Fall 2000													
700N 50-60	9092	17610	1590	893	2480	370	1900	280	510	854	80	1.600	11.40
800N 50-60	9093	19760	1550	657	1710	274	1620	283	458	765	112	1.720	3.70
900N 50-60	9094	18310	3140	717	1960	363	1600	191	586	821	84	0.920	8.30
1000N 50-60	9095	10880	2050	1040	3750	322	2930	325	725	1153	87	1.200	38.00
1100N 50-60	9096	24180	2250	647	2770	183	2080	233	709	834	88	1.510	7.60
1200N 50-60	9097	22640	2510	651	1810	228	1890	324	634	766	102	0.990	6.90
1600N 50-60	9098	19620	5940	1120	3030	471	1080	338	775	1104	244	1.860	5.30
Average		**19000**	**2719**	**818**	**2501**	**316**	**1871**	**282**	**628**	**900**	**114**	**1.400**	**11.60**
Stand. Dev.		4270	1522	200	743	97	567	54	117	160	58	0.366	11.89

Appendix 10A Tables 1-6: Bound Mineral Analysis of fine mycorrhizal oak roots from unlimed (N) and limed (K) soil at 0-10, 30-40 and 50-60 cm depths.

Table 10A-6: Analysis of bound minerals present in limed fine mycorrhizal oak roots at 50-60 cm depth.

Bound Content		Al mg/kg	Ca mg/kg	Mg mg/kg	K mg/kg	Na mg/kg	Fe mg/kg	Mn mg/kg	P mg/kg	S mg/kg	Zn mg/kg	Cd mg/kg	Pb mg/kg
Spring 1999	LNR												
1K 50-60	8960	11910	8670	1870	1440	325	2250	262	927	1463	380	2.410	33.30
2K 50-60	8961	8040	9150	1950	1730	173	2060	633	669	1093	427	2.330	24.60
3K 50-60	8962	12880	4920	1530	1500	175	2620	279	434	515	58	0.420	6.80
4K 50-60	8963	16270	6200	1280	1580	195	2870	585	645	618	184	0.470	18.40
5K 50-60	8964	12040	3860	957	1330	246	1060	774	852	720	130	1.130	4.30
6K 50-60	8965	11790	3260	1300	1810	147	746	350	628	658	168	1.250	7.00
Average		**12155**	**6010**	**1481**	**1565**	**210**	**1934**	**481**	**693**	**845**	**225**	**1.335**	**15.73**
Stand. Dev.		2630.5	2463.5	379.85	180.31	65.282	852.95	212.46	175.63	361.79	146.06	0.870	11.67
Fall 1999													
7K 50-60	8978	8780	3660	1170	1030	135	1080	170	403	500	234	0.750	12.00
8K 50-60	8979	11300	3490	1690	1550	176	2620	103	498	847	132	1.700	25.40
9K 50-60	8980	16460	3690	1530	1890	183	3520	231	451	632	154	1.910	15.10
12K 50-60	8983	14020	2340	1520	1980	214	4500	500	392	596	54	0.450	18.50
Average		**12640**	**3295**	**1478**	**1613**	**177**	**2930**	**251**	**436**	**644**	**144**	**1.203**	**17.75**
Stand. Dev.		3326.3	642.73	219.3	430.22	32.506	1452.8	174.04	48.628	146.51	74.034	0.712	5.75
Spring 2000													
100K 50-60	9032	19130	1290	1220	2370	187	2900	220	553	704	77	1.480	9.20
200K 50-60	9033	15890	1470	835	1750	191	1690	392	469	662	106	1.720	7.50
300K 50-60	9034	20880	4190	898	1110	147	1210	180	541	682	536	0.840	6.60
400K 50-60	9035	14670	1900	1380	2630	182	1770	781	481	678	317	0.960	7.50
500K 50-60	9036	18840	1660	866	1260	205	2010	270	525	661	102	0.920	6.60
600K 50-60	9037	14640	1100	1050	4610	331	1730	371	636	953	94	2.110	7.40
Average		**17342**	**1935**	**1042**	**2288**	**207**	**1885**	**369**	**534**	**723**	**205**	**1.338**	**7.47**
Stand. Dev.		2627.1	1139.4	219.34	1284.5	63.657	561.56	218.17	59.881	113.61	185.05	0.515	0.95
Fall 2000													
800K 50-60	9052	19440	2640	1610	2210	318	2730	187	454	872	216	2.730	7.30
900K 50-60	9053	17450	4790	1530	2630	273	1980	109	496	764	108	1.600	5.00
1000K 50-60	9054	20520	2920	1570	2900	270	4840	86	433	681	62	0.840	10.60
1100K 50-60	9055	20610	1920	1020	1390	288	1410	335	656	1140	79	1.210	8.50
1100K 50-60	9056	14550	1590	1330	2890	295	3200	453	576	840	76	1.250	20.90
1200K 50-60	9057	15540	2460	1320	2230	320	4460	624	632	979	81	0.900	65.70
1400K 50-60	9058	14410	4580	1420	4070	570	3030	158	548	925	255	1.410	5.10
Average		**17503**	**2986**	**1400**	**2617**	**333**	**3093**	**279**	**542**	**886**	**125**	**1.420**	**17.59**
Stand. Dev.		2728	1243.7	202.48	825.32	106.14	1234.2	200.7	85.663	149.39	77.343	0.636	21.90

Appendix 10B Tables 1-6 : Statistical Analysis of Bound Minerals

Table 10B-1: Bound minerals (mg/kg) found in unlimed (N) and limed (K) mycorrhizal oak roots at 0-10 cm depth in 1999

	Al N	Al K	Ca N	Ca K	Mg N	Mg K	K N	K K	Na N	Na K	Fe N	Fe K	Mn N	Mn K	P N	P K	S N	S K	Zn N	Zn K	Cd N	Cd K	Pb N	Pb K
Spring 1999																								
	4540	2930	12520	17890	2330	2760	1520	1000	661	514	2500	2410	361	471	1023	820	1472	1470	181	421	1.07	0.71	55.3	73.0
	6180	3980	2810	5910	849	2200	1140	857	125	126	5320	6610	646	808	676	580	1083	1089	60	49	0.58	0.56	70.7	79.7
	6410	5120	2820	8890	943	3450	1260	1180	105	188	4600	6420	810	675	747	542	984	1101	67	57	0.58	0.37	94.1	66.2
	5150	6300	1980	7890	532	2660	1010	1560	105	257	8810	4290	503	928	1074	746	1171	1422	65	133	0.39	1.13	120.0	109.0
	4310	2370	1930	9390	826	1820	1590	361	156	105	3520	1300	271	252	711	421	1104	845	49	260	0.47	0.66	82.2	39.8
	888	6910	2690	8370	970	1710	2220	1510	111	186	314	4090	460	162	599	773	1044	1160	30	638	0.59	1.07	28.7	74.6
Ave.	***4580***	***4602***	***4125***	***9723***	***1075***	***2433***	***1457***	***1078***	***211***	***229***	***4177***	***4187***	***509***	***549***	***805***	***647***	***1143***	***1181***	***75***	***260***	***0.61***	***0.75***	***75.2***	***73.7***
SD	***1997***	***1824***	***4132***	***4177***	***634***	***655***	***434***	***447***	***222***	***149***	***2868***	***2115***	***195***	***307***	***196***	***156***	***173***	***232***	***54***	***233***	***0.24***	***0.30***	***31.6***	***22.3***
tt		***0.99***		***0.00***		***0.01***		***0.18***		***0.69***		***0.99***		***0.71***		***0.09***		***0.61***		***0.11***		***0.46***		***0.9***
tinv		***0.02***		***9.66***		***4.10***		***1.54***		***0.43***		***0.01***		***0.40***		***2.13***		***0.54***		***1.93***		***0.80***		***0.1***
%		***NS***	***HS***	***>99%***	***HS***	***>99%***		***>80%***		***NS***		***NS***		***NS***	***S***	***>90%***		***NS***		***>80%***		***>50%***		***NS***
Fall 1999																								
	4350		2910		840		1150		152		3340		337		737		1051		101		0.51		63.0	
	2250	2670	4770	7560	530	2730	313	3110	79	509	1640	1560	163	222	527	618	846	1420	225	282	0.64	1.03	32.9	50.5
	5620	8010	907	5590	499	1930	1200	1810	90	204	3500	5250	189	466	633	713	1197	1377	46	115	0.32	0.49	74.0	69.7
	9090	7680	2870	2620	692	1280	1420	1960	288	154	5220	5390	363	261	1260	760	1219	1233	136	76	0.47	0.94	102.5	107.8
	8450	7370	3240	4930	775	2220	1390	1620	219	127	4430	7110	554	1450	833	659	1152	1011	77	55	0.62	0.57	96.6	73.4
	7650	5690	1350	5820	651	2690	1500	2380	143	246	4060	2870	196	709	763	647	1067	1177	42	74	0.33	0.63	88.2	55.6
Ave.	***6235***	***6284***	***2675***	***5304***	***665***	***2170***	***1162***	***2176***	***162***	***248***	***3698***	***4436***	***300***	***622***	***792***	***679***	***1089***	***1244***	***105***	***120***	***0.48***	***0.73***	***76.2***	***71.4***
SD	***2641***	***2209***	***1392***	***1788***	***134***	***599***	***437***	***592***	***80***	***153***	***1215***	***2205***	***150***	***502***	***253***	***57***	***137***	***164***	***69***	***93***	***0.14***	***0.24***	***25.7***	***22.5***
tt		***0.70***		***0.04***		***0.01***		***0.09***		***0.45***		***0.39***		***0.13***		***0.31***		***0.28***		***0.57***		***0.05***		***0.5***
tinv		***0.42***		***2.92***		***5.43***		***2.21***		***0.84***		***0.97***		***1.87***		***1.15***		***1.23***		***0.62***		***2.80***		***0.8***
%		***NS***	***HS***	***>95%***	***HS***	***>99%***	***S***	***>90%***		***>50%***		***>60%***		***>80%***		***>60%***		***>70%***		***NS***	***HS***	***>95%***		***>50%***

Table 10B-2: Bound minerals (mg/kg) found in unlimed (N) and limed (K) mycorrhizal oak roots at 0-10 cm depth in 2000

	Al N	Al K	Ca N	Ca K	Mg N	Mg K	K N	K K	Na N	Na K	Fe N	Fe K	Mn N	Mn K	P N	P K	S N	S K	Zn N	Zn K	Cd N	Cd K	Pb N	Pb K
Spring 2000																								
	7810	6180	3520	8890	947	2410	1760	1600	169	281	3090	2980	929	571	923	721	1256	1045	102	193	0.93	0.84	78.5	68.6
	5330	8140	1870	8800	777	1560	1930	1690	353	296	3290	6350	264	1070	1042	968	1396	1325	74	396	1.14	1.33	144.6	126.0
	2350	10110	4040	3040	939	1840	1230	2600	250	316	1150	5530	449	431	767	826	1159	1116	206	114	0.84	2.02	97.3	87.0
	6070	9870	2350	7660	492	1690	875	1350	161	382	2900	4180	458	363	858	791	1216	1142	136	341	0.70	1.11	102.0	100.3
	7330	12980	3670	3910	851	1810	1170	2040	223	204	6200	8460	147	563	1055	870	1467	1094	98	91	0.47	0.59	165.5	97.0
	9660	11990	4210	6180	959	2090	1610	2000	576	254	4540	6730	726	742	1203	774	1746	1240	75	90	0.40	0.53	116.9	118.7
Ave.	***6425***	***9878***	***3277***	***6413***	***828***	***1900***	***1429***	***1880***	***289***	***289***	***3528***	***5705***	***496***	***623***	***975***	***825***	***1373***	***1160***	***115***	***204***	***0.75***	***1.07***	***117***	***99.6***
SD	***2495***	***2483***	***949***	***2493***	***179***	***306***	***402***	***437***	***157***	***60***	***1701***	***1941***	***290***	***255***	***157***	***86***	***216***	***103***	***50***	***134***	***0.28***	***0.56***	***32.3***	***20.9***
tt		***0.05***		***0.06***		***0.00***		***0.13***		***1.00***		***0.02***		***0.48***		***0.08***		***0.04***		***0.21***		***0.14***		***0.2***
tinv		***2.65***		***2.41***		***10.8***		***1.80***		***0.00***		***3.49***		***0.75***		***2.21***		***2.75***		***1.44***		***1.76***		***1.7***
%	***HS***	***>95%***	***S***	***>90%***	***HS***	***>99%***		***>80%***		***NS***	***HS***	***>98%***		***>50%***	***S***	***>90%***	***HS***	***>95%***		***>70%***		***>80%***		***>80%***
Fall 2000																								
	10250	14500	13420	5300	2430	1980	2050	2770	415	320	7670	8080	911	347	907	887	2138	1426	336	205	1.23	0.69	112.5	95.7
	15300	12030	5620	8180	1630	1920	2290	1900	299	267	7310	6500	633	433	935	842	1690	1529	161	137	0.35	0.62	111.1	104.9
	11010	7850	2490	9550	803	1700	1790	2230	243	627	6520	5520	232	1720	928	1136	1652	1463	98	126	0.25	1.00	145.4	127.9
	10010	9900	2910	3860	974	1480	3500	2880	400	430	5690	6420	544	669	1118	973	1437	1323	124	150	0.62	1.72	126.2	94.4
	10650	16600	2300	4110	695	1700	1290	2800	185	303	4420	10630	189	587	1102	983	1553	1222	78	147	0.28	1.00	100.3	140.0
	2690	13880	5070	4040	914	1510	1160	2700	351	397	1740	7090	207	507	705	808	1467	1095	108	98	0.81	0.93	161.5	90.3
	5610	11030	4400	5050	1260	1800	2920	3610	609	640	2820	7250	644	359	1085	949	1567	1413	129	162	1.10	2.15	85.8	113.1
Ave.	***9360***	***12256***	***5173***	***5727***	***1244***	***1727***	***2143***	***2699***	***357***	***426***	***5167***	***7356***	***480***	***660***	***969***	***940***	***1643***	***1353***	***148***	***146***	***0.66***	***1.16***	***120***	***109***
SD	***4071***	***2974***	***3860***	***2244***	***610***	***190***	***846***	***538***	***138***	***152***	***2265***	***1648***	***277***	***482***	***147***	***109***	***236***	***151***	***87***	***33***	***0.40***	***0.56***	***26.1***	***18.7***
tt		***0.20***		***0.76***		***0.04***		***0.13***		***0.28***		***0.11***		***0.50***		***0.59***		***0.01***		***0.96***		***0.07***		***0.5***
tinv		***1.44***		***0.32***		***2.68***		***1.75***		***1.18***		***1.90***		***0.71***		***0.56***		***3.67***		***0.05***		***2.24***		***0.8***
%		***>80%***		***NS***	***HS***	***>95%***		***>80%***		***>70%***		***>80%***		***NS***		***NS***	***HS***	***>98%***		***NS***	***S***	***>90%***		***>50%***

Statistical Analysis Including: Ave.=Average, SD=Standard Deviation, tt=Student t-test, inv= inverse of t-test, %=Significant Difference, S= Significant, HS=Highly Significant, NS=Not Significant.

Appendix 10B Tables 1-6 : Statistical Analysis of Bound Minerals

Table 10B-3: Bound minerals (mg/kg) found in unlimed (N) and limed (K) mycorrhizal oak roots at 30-40 cm depth in 1999

	Al N	Al K	Ca N	Ca K	Mg N	Mg K	K N	K K	Na N	Na K	Fe N	Fe K	Mn N	Mn K	P N	P K	S N	S K	Zn N	Zn K	Cd N	Cd K	Pb N	Pb K
Spring 1999																								
	12310		5000		999		1870		308		886		345		919		1152		404		2.70		24.5	
	10140	17920	8900	9750	1630	2420	1220	2100	248	875	1010	1400	417	426	505	958	725	1380	220	502	0.93	3.79	21.9	31.7
	10340	13800	7840	11870	1110	2270	1180	2120	290	507	763	1950	596	529	504	553	738	873	278	598	1.20	2.30	19.3	16.4
	16230	15200	2320	7180	569	2140	990	1420	102	431	1550	1160	1100	285	779	676	715	1760	182	309	2.11	1.29	10.7	16.0
	8100	12390	4820	5230	1060	1590	610	726	133	139	647	1350	818	419	563	504	732	948	293	298	1.93	0.74	6.7	12.7
	3220	10260	3860	6840	1020	1090	2550	1170	209	161	1880	501	122	591	601	1236	842	923	86	192	0.64	1.18	26.8	8.0
Ave.	***10057***	***13914***	***5457***	***8174***	***1065***	***1902***	***1403***	***1507***	***215***	***423***	***1123***	***1272***	***566***	***450***	***645***	***785***	***817***	***1177***	***244***	***380***	***1.59***	***1.86***	***18.3***	***17.0***
SD	***4332***	***2889***	***2471***	***2626***	***339***	***552***	***695***	***604***	***84***	***300***	***486***	***522***	***351***	***117***	***168***	***307***	***170***	***384***	***108***	***165***	***0.79***	***1.22***	***8.0***	***8.9***
tt		***0.05***		***0.04***		***0.03***		***0.66***		***0.14***		***0.83***		***0.50***		***0.26***		***0.08***		***0.05***		***0.53***		***1.0***
tinv		***2.76***		***3.02***		***3.20***		***0.47***		***1.86***		***0.23***		***0.75***		***1.32***		***2.31***		***2.88***		***0.69***		***0.0***
%	***S***	***>90%***	***HS***	***>95%***	***HS***	***>95%***		***NS***		***>80%***		***NS***		***>50%***		***>70%***	***S***	***>90%***	***HS***	***>95%***		***NS***		***NS***
Fall 1999																								
	12770	12010	3990	2790	967	1740	1970	1690	287	200	1600	1500	369	249	627	606	933	693	195	220	1.81	1.03	12.6	17.0
	16260	16830	7320	2690	1450	1470	1670	1790	912	174	1230	2760	406	209	463	481	1816	688	166	107	0.82	1.03	4.4	10.3
	15240	18460	1530	2320	838	1580	2150	1790	106	206	2630	4130	505	276	546	461	658	631	123	137	1.85	1.60	10.8	16.1
	18430	3050	4280	13310	729	1790	1270	873	138	209	3100	1690	426	437	544	617	681	888	107	325	1.18	0.63	13.8	34.6
	16730	15970	3520	2750	704	1700	1950	2270	144	167	2360	3160	453	814	785	525	769	661	169	76	2.11	0.72	8.1	10.1
	16730	16770	2190	3460	463	1450	1450	1750	83	215	2610	3850	376	863	544	554	735	789	187	80	2.05	0.94	8.8	19.4
Ave.	***16027***	***13848***	***3805***	***4553***	***859***	***1622***	***1743***	***1694***	***278***	***195***	***2255***	***2848***	***423***	***475***	***585***	***541***	***932***	***725***	***158***	***158***	***1.64***	***0.99***	***9.8***	***17.9***
SD	***1900***	***5713***	***2024***	***4306***	***334***	***143***	***339***	***453***	***318***	***20***	***703***	***1087***	***51***	***293***	***111***	***64***	***444***	***96***	***35***	***98***	***0.52***	***0.34***	***3.4***	***9.0***
tt		***0.46***		***0.70***		***0.00***		***0.73***		***0.56***		***0.26***		***0.69***		***0.40***		***0.34***		***0.99***		***0.04***		***0.0***
tinv		***0.80***		***0.40***		***4.84***		***0.36***		***0.62***		***1.26***		***0.42***		***0.92***		***1.07***		***0.01***		***2.72***		***2.9***
%		***>50%***		***NS***	***HS***	***>99%***		***NS***		***NS***		***>70%***		***NS***		***>60%***		***>60%***		***NS***	***HS***	***>95%***	***HS***	***>95%***

Table 10B-4: Bound minerals (mg/kg) found in unlimed (N) and limed (K) mycorrhizal oak roots at 30-40 cm depth in 2000

	Al N	Al K	Ca N	Ca K	Mg N	Mg K	K N	K K	Na N	Na K	Fe N	Fe K	Mn N	Mn K	P N	P K	S N	S K	Zn N	Zn K	Cd N	Cd K	Pb N	Pb K
Spring 2000																								
	21270	18780	1360	1370	630	1540	1950	1430	314	197	2160	1970	863	325	711	566	744	854	130	109	1.32	1.97	11.0	18.8
	3230	16910	4190	2980	871	1290	2480	1730	276	222	1380	1810	295	481	638	624	992	869	182	163	0.76	1.76	66.2	25.0
	21400	21190	1820	2590	568	1550	1100	1210	178	165	1290	1340	351	270	600	592	701	746	122	133	1.08	1.41	31.5	4.9
	18000	20240	2710	2830	719	1540	873	1150	185	142	872	1920	697	998	696	676	828	912	119	83	1.48	1.10	11.7	27.1
	17350	12880	697	2100	764	1360	3230	2700	181	170	1870	1960	262	289	556	407	757	662	61	58	0.58	1.04	7.2	8.2
	17610	20390	2640	1820	697	1370	1360	1410	189	334	1010	2630	524	675	546	590	789	843	115	76	1.72	1.63	7.3	11.8
Ave.	***16477***	***18398***	***2236***	***2282***	***708***	***1442***	***1832***	***1605***	***221***	***205***	***1430***	***1938***	***499***	***506***	***625***	***576***	***802***	***814***	***122***	***104***	***1.16***	***1.49***	***22.5***	***16.0***
SD	***6739***	***3097***	***1226***	***626***	***105***	***115***	***902***	***574***	***59***	***69***	***497***	***413***	***242***	***285***	***70***	***91***	***103***	***93***	***39***	***39***	***0.43***	***0.37***	***23.3***	***9.1***
tt		***0.49***		***0.91***		***0.00***		***0.25***		***0.68***		***0.13***		***0.95***		***0.19***		***0.77***		***0.07***		***0.17***		***0.5***
tinv		***0.74***		***0.11***		***8.53***		***1.31***		***0.43***		***1.79***		***0.06***		***1.50***		***0.31***		***2.28***		***1.61***		***0.7***
%		***>50%***		***NS***	***HS***	***>99%***		***>70%***		***NS***		***>80%***		***NS***		***>80%***		***NS***	***S***	***>90%***		***>80%***		***NS***
Fall 2000																								
	15180	17600	4600	2980	1180	1160	2200	1880	311	243	2110	1640	716	258	550	476	894	790	115	242	1.28	2.02	11.4	8.4
	21960	17900	2980	3070	651	1010	1840	1690	244	222	972	1680	274	206	578	549	758	790	191	90	1.20	1.70	5.5	12.4
	20480	16490	2490	2130	717	1140	2210	1180	300	239	2700	3320	300	213	585	594	783	1101	122	48	1.71	0.73	7.5	14.5
	26420	19660	2370	2880	558	1240	1180	2110	225	431	1960	2500	272	438	835	628	972	944	83	161	1.35	2.42	14.3	13.1
	18400	21510	1930	2910	488	1340	999	2000	151	339	1180	4710	655	160	596	547	757	756	133	69	1.20	1.26	7.4	12.2
	10220	17640	3300	1850	686	1180	1940	2340	365	309	6550	4370	53	361	601	426	799	666	180	92	1.18	1.29	43.4	7.9
	17490	17090	3510	4920	957	1430	2870	2690	433	431	1970	1940	544	268	625	635	971	923	187	193	1.98	1.21	9.5	7.7
Ave.	***18593***	***18270***	***3026***	***2963***	***748***	***1214***	***1891***	***1984***	***290***	***316***	***2492***	***2880***	***402***	***272***	***624***	***551***	***848***	***853***	***144***	***128***	***1.41***	***1.52***	***14.1***	***10.9***
SD	***5151***	***1731***	***886***	***982***	***241***	***138***	***641***	***480***	***93***	***89***	***1882***	***1276***	***241***	***97***	***96***	***78***	***96***	***145***	***42***	***72***	***0.31***	***0.57***	***13.2***	***2.8***
tt		***0.87***		***0.89***		***0.00***		***0.75***		***0.58***		***0.57***		***0.30***		***0.06***		***0.93***		***0.64***		***0.73***		***0.6***
tinv		***0.17***		***0.14***		***4.52***		***0.34***		***0.59***		***0.60***		***1.14***		***2.26***		***0.09***		***0.49***		***0.36***		***0.6***
%		***NS***		***NS***	***HS***	***>99%***		***NS***		***NS***		***NS***		***>60%***	***S***	***>90%***		***NS***		***NS***		***NS***		***NS***

Statistical Analysis Including: Ave.=Average, SD=Standard Deviation, tt=Student t-test, inv= inverse of t-test, %=Significant Difference, S= Significant, HS=Highly Significant, NS=Not Significant.

Appendix 10B Tables 1-6 : Statistical Analysis of Bound Minerals

Table 10B-5: Bound minerals (mg/kg) found in unlimed (N) and limed (K) mycorrhizal oak roots at 50-60 cm depth in 1999

	Al N	Al K	Ca N	Ca K	Mg N	Mg K	K N	K K	Na N	Na K	Fe N	Fe K	Mn N	Mn K	P N	P K	S N	S K	Zn N	Zn K	Cd N	Cd K	Pb N	Pb K
Spring 1999																								
	14920	11910	8560	8670	1250	1870	1460	1440	349	325	1080	2250	424	262	719	927	1725	1463	360	380	1.35	2.41	15.2	33.3
	10210	8040	5580	9150	1120	1950	789	1730	216	173	1390	2060	543	633	507	669	1233	1093	106	427	0.96	2.33	5.4	24.6
	12160	12880	5040	4920	816	1530	721	1500	216	175	1090	2620	466	279	484	434	840	515	134	58	1.12	0.42	5.6	6.8
	13390	16270	4860	6200	806	1280	910	1580	176	195	885	2870	628	585	621	645	681	618	332	184	1.75	0.47	3.6	18.4
	13550	12040	3350	3860	515	957	1170	1330	149	246	2330	1060	197	774	468	852	510	720	73	130	0.58	1.13	14.0	4.3
	15850	11790	2920	3260	699	1300	2430	1810	296	147	991	746	111	350	579	628	834	658	115	168	0.79	1.25	8.0	7.0
Ave.	***13347***	***12155***	***5052***	***6010***	***868***	***1481***	***1247***	***1565***	***234***	***210***	***1294***	***1934***	***395***	***481***	***563***	***693***	***971***	***845***	***187***	***225***	***1.09***	***1.34***	***8.6***	***15.7***
SD	***2001.6***	***2630.5***	***2003.2***	***2463.5***	***272***	***380***	***640***	***180***	***75***	***65.3***	***535***	***852.95***	***201***	***212***	***96.3***	***176***	***440***	***362***	***125***	***146***	***0.42***	***0.87***	***4.8***	***11.7***
tt		***0.31***		***0.15***		***0.00***		***0.24***		***0.51***		***0.25***		***0.50***		***0.10***		***0.16***		***0.59***		***0.59***		***0.2***
tinv		***1.14***		***1.71***		***10.3***		***1.32***		***0.71***		***1.30***		***0.73***		***2.03***		***1.64***		***0.58***		***0.58***		***1.5***
%		***>60%***		***>80%***	***HS***	***>99%***		***>70%***		***NS***		***>70%***		***>50%***	***S***	***>90%***		***>80%***		***NS***		***NS***		***>70%***
Fall 1999																								
	11800		2840		879		1990		181		1850		291		588		657		163		1.91		7.2	
	9370	8780	5700	3660	1250	1170	1517	1030	574	135	1080	1080	359	170	363	403	1015	500	124	234	1.08	0.75	8.7	12.0
	14880	11300	1760	3490	1040	1690	1560	1550	188	176	2910	2620	412	103	506	498	629	847	160	132	2.13	1.70	13.4	25.4
	10980	16460	6120	3690	1240	1530	811	1890	198	183	761	3520	509	231	457	451	646	632	173	154	0.90	1.91	6.1	15.1
	16690	14020	3900	2340	814	1520	2290	1980	184	214	2930	4500	554	500	752	392	678	596	170	54	1.94	0.45	15.1	18.5
Ave.	***12744***	***12640***	***4064***	***3295***	***1045***	***1478***	***1634***	***1613***	***265***	***177***	***1906***	***2930***	***425***	***251***	***533***	***436***	***725***	***644***	***158***	***144***	***1.59***	***1.20***	***10.1***	***17.8***
SD	***2980***	***3326.3***	***1853***	***642.73***	***201***	***219***	***560***	***430***	***173***	***32.5***	***1007***	***1452.8***	***107***	***174***	***147***	***48.6***	***163***	***147***	***20***	***74***	***0.56***	***0.71***	***3.9***	***5.7***
tt		***0.88***		***0.34***		***0.12***		***0.86***		***0.40***		***0.25***		***0.04***		***0.43***		***0.57***		***0.79***		***0.59***		***0.0***
tinv		***0.17***		***1.13***		***2.15***		***0.19***		***0.99***		***1.42***		***3.63***		***0.90***		***0.64***		***0.28***		***0.61***		***3.2***
%		***NS***		***>60%***		***>80%***		***NS***		***>60%***		***>70%***	***S***	***>90%***		***>50%***		***NS***		***NS***		***NS***	***S***	***>90%***

Table 10B-6: Bound minerals (mg/kg) found in unlimed (N) and limed (K) mycorrhizal oak roots at 50-60 cm depth in 2000

	Al N	Al K	Ca N	Ca K	Mg N	Mg K	K N	K K	Na N	Na K	Fe N	Fe K	Mn N	Mn K	P N	P K	S N	S K	Zn N	Zn K	Cd N	Cd K	Pb N	Pb K
Spring 2000																								
	18080	19130	1570	1290	627	1220	3520	2370	130	187	870	2900	516	220	558	553	864	704	84	77	0.93	1.48	10.4	9.2
	14670	15890	1310	1470	458	835	1560	1750	137	191	2450	1690	172	392	571	469	753	662	156	106	1.53	1.72	14.6	7.5
	9010	20880	570	4190	770	898	2720	1110	402	147	3200	1210	170	180	527	541	717	682	125	536	1.40	0.84	18.0	6.6
	20500	14670	1190	1900	549	1380	1840	2630	216	182	767	1770	786	781	638	481	741	678	74	317	0.91	0.96	2.5	7.5
	13570	18840	2280	1660	808	866	1900	1260	217	205	892	2010	393	270	626	525	740	661	119	102	1.05	0.92	7.1	6.6
	21110	14640	514	1100	588	1050	1800	4610	98	331	2880	1730	334	371	509	636	674	953	65	94	1.18	2.11	12.3	7.4
Ave.	***16157***	***17342***	***1239***	***1935***	***633***	***1042***	***2223***	***2288***	***200***	***207***	***1843***	***1885***	***395***	***369***	***572***	***534***	***748***	***723***	***104***	***205***	***1.17***	***1.34***	***10.8***	***7.5***
SD	***4627.6***	***2627.1***	***659.37***	***1139.4***	***134***	***219***	***748***	***1284***	***110***	***63.7***	***1122***	***561.56***	***233***	***218***	***51.887***	***59.9***	***63.3***	***114***	***35***	***185***	***0.25***	***0.52***	***5.5***	***1.0***
tt		***0.69***		***0.31***		***0.02***		***0.92***		***0.92***		***0.95***		***0.73***		***0.42***		***0.71***		***0.24***		***0.46***		***0.2***
tinv		***0.42***		***1.12***		***3.46***		***0.10***		***0.11***		***0.07***		***0.37***		***0.89***		***0.39***		***1.35***		***0.81***		***1.4***
%		***NS***		***>60%***	***HS***	***>98%***		***NS***		***NS***		***NS***		***NS***		***>50%***		***NS***		***>70%***		***>50%***		***>80%***
Fall 2000																								
	17610	19440	1590	2640	893	1610	2480	2210	370	318	1900	2730	280	187	510	454	854	872	80	216	1.60	2.73	11.4	7.3
	19760	17450	1550	4790	657	1530	1710	2630	274	273	1620	1980	283	109	458	496	765	764	112	108	1.72	1.60	3.7	5.0
	18310	20520	3140	2920	717	1570	1960	2900	363	270	1600	4840	191	86	586	433	821	681	84	62	0.92	0.84	8.3	10.6
	10880	20610	2050	1920	1040	1020	3750	1390	322	288	2930	1410	325	335	725	656	1153	1140	87	79	1.20	1.21	38.0	8.5
	24180	14550	2250	1590	647	1330	2770	2890	183	295	2080	3200	233	453	709	576	834	840	88	76	1.51	1.25	7.6	20.9
	22640	15540	2510	2460	651	1320	1810	2230	228	320	1890	4460	324	624	634	632	766	979	102	81	0.99	0.90	6.9	65.7
	19620	14410	5940	4580	1120	1420	3030	4070	471	570	1080	3030	338	158	775	548	1104	925	244	255	1.86	1.41	5.3	5.1
Ave.	***19000***	***17503***	***2719***	***2986***	***818***	***1400***	***2501***	***2617***	***316***	***333***	***1871***	***3093***	***282***	***279***	***628***	***542***	***900***	***886***	***114***	***125***	***1.40***	***1.42***	***11.6***	***17.6***
SD	***4270***	***2728***	***1522***	***1243.7***	***200***	***202***	***743***	***825***	***97***	***106***	***567***	***1234.2***	***54***	***201***	***117***	***85.7***	***160***	***149***	***58***	***77.3***	***0.37***	***0.64***	***11.9***	***21.9***
tt		***0.57***		***0.65***		***0.00***		***0.81***		***0.59***		***0.09***		***0.97***		***0.05***		***0.78***		***0.61***		***0.92***		***0.6***
tinv		***0.60***		***0.47***		***4.73***		***0.26***		***0.56***		***2.05***		***0.04***		***2.49***		***0.29***		***0.54***		***0.10***		***0.6***
%		***NS***		***NS***	***HS***	***>99%***		***NS***		***NS***	***S***	***>90%***		***NS***	***HS***	***>95%***		***NS***		***NS***		***NS***		***NS***

Statistical Analysis Including: Ave.=Average, SD=Standard Deviation, tt=Student t-test, inv= inverse of t-test, %=Significant Difference, S= Significant, HS=Highly Significant, NS=Not Significant.

Appendix 10C Tables 1-4 : % Significant Difference of Bound Minerals with respect to season, soil depth and liming.

Table 10C-1: Spring 1999 Bound Minerals comparing 0-10/30-40, 30-40/50-60 and 0-10/50-60 cm depths.

	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn	Cd	Cd	Pb	Pb
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
0-10	4540	2930	12520	17890	2330	2760	1520	1000	661	514	2500	2410	361	471	1023	820	1472	1470	181	421	1.07	0.71	55.3	73.0
	6180	3980	2810	5910	849	2200	1140	857	125	126	5320	6610	646	808	676	580	1083	1089	60	49	0.58	0.56	70.7	79.7
	6410	5120	2820	8890	943	3450	1260	1180	105	188	4600	6420	810	675	747	542	984	1101	67	57	0.58	0.37	94.1	66.2
	5150	6300	1980	7890	532	2660	1010	1560	105	257	8810	4290	503	928	1074	746	1171	1422	65	133	0.39	1.13	120.0	109.0
	4310	2370	1930	9390	826	1820	1590	361	156	105	3520	1300	271	252	711	421	1104	845	49	260	0.47	0.68	82.2	39.8
	888	6910	2690	8370	970	1710	2220	1510	111	186	314	4090	460	162	599	773	1044	1160	30	638	0.59	1.07	28.7	74.6
30-40	12310		5000		999		1870		308		886		345		919		1152		404		2.70		24.5	
	10140	17920	8900	9750	1630	2420	1220	2100	248	875	1010	1400	417	426	505	958	725	1380	220	502	0.93	3.79	21.9	31.7
	10340	13800	7840	11870	1110	2270	1180	2120	290	507	763	1950	596	529	504	553	738	873	278	598	1.20	2.30	19.3	16.4
	16230	15200	2320	7180	569	2140	990	1420	102	431	1550	1160	1100	285	779	676	715	1760	182	309	2.11	1.29	10.7	16.0
	8100	12390	4820	5230	1060	1590	610	726	133	139	647	1350	818	419	563	504	732	948	293	298	1.93	0.74	6.7	12.7
	3220	10260	3860	6840	1020	1090	2550	1170	209	161	1880	501	122	591	601	1236	842	923	86	192	0.64	1.18	26.8	8.0
50-60	14920	11910	8560	8670	1250	1870	1460	1440	349	325	1080	2250	424	262	719	927	1725	1463	360	380	1.35	2.41	15.2	33.3
	10210	8040	5580	9150	1120	1950	789	1730	216	173	1390	2060	543	633	507	669	1233	1093	106	427	0.96	2.33	5.4	24.6
	12160	12880	5040	4920	816	1530	721	1500	216	175	1090	2620	466	279	484	434	840	515	134	58	1.12	0.42	5.6	6.8
	13390	16270	4860	6200	806	1280	910	1580	176	195	885	2870	628	585	621	645	681	618	332	184	1.75	0.47	3.6	18.4
	13550	12040	3350	3860	515	957	1170	1330	149	246	2330	1060	197	774	468	852	510	720	73	130	0.58	1.13	14.0	4.3
	15850	11790	2920	3260	699	1300	2430	1810	296	147	991	746	111	350	579	628	834	658	115	168	0.79	1.25	8.0	7.0
0-10/30-40																								
tt	0.031	0.006	0.047	0.957	0.137	0.113	0.580	0.245	0.12	0.14	0.079	0.022	0.741	0.579	0.028	0.174	0.002	0.687	0.01	0.43	0.06	0.16	0.03	0.01
tinv-4	3.247	5.296	2.831	0.057	1.855	2.022	0.601	1.363	1.94	1.81	2.339	3.617	0.354	0.603	3.386	1.651	7.147	0.434	4.72	0.87	2.61	1.73	3.48	5.18
%	>95%	>99%	>95%	NS	>80%	>80%	NS	>70%	>80%	>70%	>90%	>95%	NS	NS	>90%	>80%	>99%	NS	>99%	>50%	>90%	>80%	>95%	>99%
30-40/50-60																								
tt	0.268	0.459	0.309	0.085	0.110	0.057	0.595	0.760	0.67	0.17	0.733	0.142	0.190	0.606	0.120	0.423	0.599	0.058	0.42	0.11	0.30	0.16	0.11	0.11
tinv-4	1.286	0.818	1.164	2.280	2.047	2.647	0.577	0.326	0.46	1.68	0.366	1.823	1.575	0.559	1.969	0.892	0.570	2.639	0.90	2.03	1.19	1.71	2.08	2.04
%	>70%	>50%	>60%	>90%	>80%	>90%	NS	NS	NS	>80%	NS	>80%	>80%	NS	>80%	>50%	NS	>90%	>50%	>80%	>80%	>80%	>80%	>80%
0-10/50-60																								
tt	0.002	0.001	0.421	0.082	0.355	0.013	0.122	0.022	0.76	0.69	0.064	0.033	0.221	0.654	0.009	0.630	0.265	0.060	0.03	0.77	0.05	0.20	0.00	0.00
tinv-5	5.619	7.342	0.877	2.167	1.018	3.765	1.858	3.272	0.32	0.42	2.365	2.909	1.398	0.476	4.122	0.513	1.256	2.427	2.93	0.31	2.57	1.48	4.80	7.09
%	>99%	>99%	>50%	>90%	>60%	>98%	>80%	>95%	NS	NS	>95%	>95%	>70%	NS	>99%	NS	>70%	>90%	>95%	NS	>90%	>98%	>99%	>99%

Table 10C-2: Fall 1999 Bound Minerals comparing 0-10/30-40, 30-40/50-60 and 0-10/50-60 cm depths.

	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn	Cd	Cd	Pb	Pb
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
0-10	4350		2910		840		1150		152		3340		337		737		1051		101		0.51		63.0	
	2250	2670	4770	7560	530	2730	313	3110	79	509	1640	1560	163	222	527	618	846	1420	225	282	0.64	1.03	32.9	50.5
	5620	8010	907	5590	499	1930	1200	1810	90	204	3500	5250	189	466	633	713	1197	1377	46	115	0.32	0.49	74.0	69.7
	9090	7680	2870	2620	692	1280	1420	1960	288	154	5220	5390	363	281	1260	760	1219	1233	136	76	0.47	0.94	102.5	107.8
	8450	7370	3240	4930	775	2220	1390	1620	219	127	4430	7110	554	1450	833	659	1152	1011	77	55	0.62	0.57	96.6	73.4
	7650	5690	1350	5820	651	2690	1500	2380	143	246	4060	2870	196	709	783	647	1067	1177	42	74	0.33	0.63	88.2	55.6
30-40	12770	12010	3990	2790	967	1740	1970	1690	287	200	1600	1500	369	249	627	606	933	693	195	220	1.81	1.03	12.6	17.0
	16260	16830	7320	2690	1450	1470	1670	1790	912	174	1230	2760	406	209	463	481	1816	688	166	107	0.82	1.03	4.4	10.3
	15240	18460	1530	2320	838	1580	2150	1790	106	206	2630	4130	505	276	546	461	658	631	123	137	1.85	1.60	10.8	16.1
	18430	3050	4280	13310	729	1790	1270	873	138	209	3100	1690	426	437	544	617	681	888	107	325	1.18	0.63	13.8	34.6
	16730	15970	3520	2750	704	1700	1950	2270	144	167	2360	3160	453	814	785	525	769	661	169	76	2.11	0.72	8.1	10.1
	16730	16770	2190	3460	463	1450	1450	1750	83	215	2610	3850	376	863	544	554	735	789	187	80	2.05	0.94	8.8	19.4
50-60	11800		2840		879		1990		181		1850		291		588		657		163		1.91		7.2	
	9370	8780	5700	3660	1250	1170	1517	1030	574	135	1080	1080	359	170	363	403	1015	500	124	234	1.08	0.75	8.7	12.0
	14880	11300	1760	3490	1040	1690	1560	1550	188	176	2910	2620	412	103	506	498	629	847	160	132	2.13	1.70	13.4	25.4
	10980	16460	6120	3690	1240	1530	811	1890	198	183	761	3520	509	231	457	451	646	632	173	154	0.90	1.91	6.1	15.1
	16690	14020	3900	2340	814	1520	2290	1980	184	214	2930	4500	554	500	752	392	678	596	170	54	1.94	0.45	15.1	18.5
0-10/30-40																								
tt	0.001	0.072	0.045	0.894	0.355	0.155	0.138	0.252	0.57	0.50	0.014	0.298	0.128	0.532	0.146	0.005	0.597	0.005	0.30	0.73	0.02	0.35	0.00	0.00
tinv-4	9.956	2.429	2.870	0.142	1.045	1.748	1.851	1.339	0.62	0.75	4.145	1.197	1.915	0.684	1.800	5.715	0.574	5.513	1.18	0.37	3.84	1.06	6.17	7.69
%	>99%	>90%	>95%	NS	>60%	>80%	>80%	>70%	NS	>50%	>98%	>70%	>80%	NS	>60%	>99%	NS	>99%	>60%	NS	>98%	>60%	>99%	>99%
30-40/50-60																								
tt	0.068	0.820	0.374	0.467	0.004	0.223	0.743	0.867	0.19	0.33	0.217	0.785	0.802	0.038	0.510	0.022	0.794	0.085	0.54	0.88	0.59	0.69	0.84	0.50
tinv-3	2.790	0.248	1.042	0.830	8.197	1.532	0.360	0.183	1.67	1.16	1.557	0.298	0.273	3.552	0.746	4.402	0.285	2.535	0.68	0.17	0.61	0.44	0.23	0.77
%	>90%	NS	>60%	>50%	>98%	>70%	NS	NS	>80%	>60%	>70%	NS	NS	>95%	NS	>95%	NS	>90%	NS	NS	NS	NS	NS	>50%
0-10/50-60																								
tt	0.034	0.070	0.162	0.208	0.039	0.200	0.598	0.228	0.50	0.85	0.019	0.190	0.224	0.158	0.106	0.001	0.018	0.018	0.03	0.13	0.05	0.19	0.00	0.01
tinv-3	3.709	2.761	1.848	1.601	3.503	1.635	0.588	1.509	0.77	0.21	4.591	1.690	1.530	1.874	2.288	12.398	4.712	4.755	3.74	2.06	3.20	1.67	12.90	6.36
%	>95%	>90%	>80%	>70%	>90%	>70%	NS	>70%	>50%	NS	>98%	>80%	>70%	>80%	>80%	>99%	>98%	>98%	>95%	>80%	>90%	>80%	>99%	>99%

tt=Student t-test, tinv= inverse of t-test, %=significant difference, NS=not significant

Appendix 10C Tables 1-4 : % Significant Difference of Bound Minerals with respect to season, soil depth and liming.

Table 10C-3: Spring 2000 Bound Minerals comparing 0-10/30-40, 30-40/50-60 and 0-10/50-60 cm depths.

	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn	Cd	Cd	Pb	Pb
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
0-10	7810	6180	3520	8890	947	2410	1760	1600	169	281	3090	2980	929	571	923	721	1256	1045	102	193	0.93	0.84	78.5	68.6
	5330	8140	1870	8800	777	1560	1930	1690	353	296	3290	6350	284	1070	1042	968	1396	1325	74	396	1.14	1.33	144.6	126.0
	2350	10110	4040	3040	939	1840	1230	2600	250	316	1150	5530	449	431	767	826	1159	1116	206	114	0.84	2.02	97.3	87.0
	6070	9870	2350	7660	492	1690	875	1350	161	382	2900	4180	458	363	858	791	1216	1142	136	341	0.70	1.11	102.0	100.3
	7330	12980	3670	3910	851	1810	1170	2040	223	204	6200	8460	147	563	1055	870	1467	1094	98	91	0.47	0.59	165.5	97.0
	9660	11990	4210	6180	959	2090	1610	2000	576	254	4540	6730	726	742	1203	774	1746	1240	75	90	0.40	0.53	116.9	118.7
30-40	21270	18780	1360	1370	630	1540	1950	1430	314	197	2160	1970	863	325	711	566	744	854	130	109	1.32	1.97	11.0	18.8
	3230	16910	4190	2980	871	1290	2480	1730	276	222	1380	1810	295	481	638	624	992	869	182	163	0.76	1.76	66.2	25.0
	21400	21190	1820	2590	568	1550	1100	1210	178	165	1290	1340	351	270	600	592	701	746	122	133	1.08	1.41	31.5	4.9
	18000	20240	2710	2830	719	1540	873	1150	185	142	872	1920	697	998	696	676	828	912	119	83	1.48	1.10	11.7	27.1
	17350	12880	697	2100	764	1360	3230	2700	181	170	1870	1960	262	289	556	407	757	662	61	58	0.58	1.04	7.2	8.2
	17610	20390	2640	1820	697	1370	1360	1410	189	334	1010	2630	524	675	546	590	789	843	115	76	1.72	1.63	7.3	11.8
50-60	18080	19130	1570	1290	627	1220	3520	2370	130	187	870	2900	516	220	558	553	884	704	84	77	0.93	1.48	10.4	9.2
	14670	15890	1310	1470	458	835	1560	1750	137	191	2450	1690	172	392	571	469	753	682	156	106	1.53	1.72	14.6	7.5
	9010	20880	570	4190	770	898	2720	1110	402	147	3200	1210	170	180	527	541	717	682	125	536	1.40	0.84	18.0	6.6
	20500	14670	1190	1900	549	1380	1840	2630	216	182	767	1770	786	781	638	481	741	678	74	317	0.91	0.96	2.5	7.5
	13570	18840	2280	1660	808	866	1900	1260	217	205	892	2010	393	270	626	525	740	661	119	102	1.05	0.92	7.1	6.6
	21110	*14640*	*514*	*1100*	*588*	*1050*	*1800*	*4610*	*98*	*331*	*2880*	*1730*	*334*	*371*	*509*	*636*	*674*	*953*	*65*	*94*	*1.18*	*2.11*	*12.3*	*7.4*
0-10/30-40																								
tt	0.017	0.006	0.258	0.012	0.279	0.010	0.302	0.369	0.39	0.12	0.026	0.005	0.963	0.514	0.008	0.006	0.001	0.001	0.83	0.09	0.15	0.19	0.001	0.000
tinv-5	3.495	4.843	1.277	3.892	1.215	3.985	1.150	0.988	0.94	1.90	3.134	4.832	0.049	0.702	4.213	4.852	8.312	7.728	0.23	2.10	1.72	1.53	8.847	9.937
%	>98%	>99%	>70%	>80%	>70%	>98%	>60%	>60%	>60%	>80%	>95%	>99%	NS	NS	>99%	>99%	>99%	>99%	NS	>90%	>80%	>80%	>99%	>99%
30-40/50-60																								
tt	0.927	0.577	0.194	0.463	0.423	0.002	0.481	0.340	0.75	0.86	0.505	0.832	0.222	0.023	0.132	0.429	0.334	0.151	0.35	0.22	0.97	0.38	0.23	0.06
tinv-5	0.097	0.596	1.499	0.795	0.873	5.741	0.762	1.055	0.34	0.18	0.719	0.223	1.395	3.245	1.800	0.860	1.069	1.694	1.03	1.38	0.04	0.96	1.38	2.41
%	NS	NS	>80%	>50%	>50%	>99%	>50%	>60%	NS	NS	NS	NS	>70%	>95%	>80%	>50%	>60%	>80%	>60%	>70%	NS	>60%	>70%	>90%
0-10/50-60																								
tt	0.001	0.005	0.011	0.022	0.040	0.001	0.058	0.528	0.38	0.11	0.143	0.009	0.480	0.146	0.002	0.003	0.002	0.000	0.66	0.99	0.01	0.50	0.00	0.00
tinv-5	7.767	4.754	3.902	3.263	2.753	6.817	2.443	0.678	0.96	1.92	1.736	4.165	0.763	1.720	5.674	5.460	6.045	8.282	0.47	0.01	3.65	0.72	7.87	10.58
%	>99%	>99%	>98%	>95%	>95%	>99%	>90%	NS	>60%	>80%	>80%	>99%	>50%	>80%	>99%	>99%	>99%	>99%	NS	NS	>80%	NS	>99%	>99%

Table 10C-4: Fall 2000 Bound Minerals comparing 0-10/30-40, 30-40/50-60 and 0-10/50-60 cm depths.

	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn	Cd	Cd	Pb	Pb
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
0-10	10250	14500	13420	5300	2430	1980	2050	2770	415	320	7670	8080	911	347	907	887	2138	1426	336	205	1.23	0.69	112.5	95.7
	15300	12030	5620	8180	1630	1920	2290	1900	299	267	7310	6500	633	433	935	842	1690	1529	161	137	0.35	0.62	111.1	104.9
	11010	7850	2490	9550	803	1700	1790	2230	243	627	6520	5520	232	1720	928	1136	1652	1463	98	126	0.25	1.00	145.4	127.9
	10010	9900	2910	3860	974	1480	3500	2880	400	430	5690	6420	544	669	1118	973	1437	1323	124	150	0.62	1.72	126.2	94.4
	10650	16600	2300	4110	695	1700	1290	2800	185	303	4420	10630	189	587	1102	983	1553	1222	78	147	0.28	1.00	100.3	140.0
	2690	13880	5070	4040	914	1510	1160	2700	351	397	1740	7090	207	507	705	808	1467	1095	108	98	0.81	0.93	161.5	90.3
	5610	11030	4400	5050	1260	1800	2920	3610	609	640	2820	7250	644	359	1085	949	1567	1413	129	162	1.10	2.15	85.8	113.1
30-40	15180	17600	4600	2980	1180	1160	2200	1880	311	243	2110	1640	716	258	550	476	894	790	115	242	1.28	2.02	11.4	8.4
	21960	17900	2980	3070	651	1010	1840	1690	244	222	972	1680	274	206	578	549	758	790	191	90	1.20	1.70	5.5	12.4
	20480	16490	2490	2130	717	1140	2210	1180	300	239	2700	3320	300	213	585	594	783	1101	122	48	1.71	0.73	7.5	14.5
	26420	19660	2370	2880	558	1240	1180	2110	225	431	1960	2500	272	438	835	628	972	944	83	161	1.35	2.42	14.3	13.1
	18400	21510	1930	2910	488	1340	999	2000	151	339	1180	4710	655	160	596	547	757	756	133	69	1.20	1.26	7.4	12.2
	10220	17640	3300	1850	686	1180	1940	2340	365	309	6550	4370	53	361	601	426	799	666	180	92	1.18	1.29	43.4	7.9
	17490	17090	3510	4920	957	1430	2870	2690	433	431	1970	1940	544	268	625	635	971	923	187	193	1.98	1.21	9.5	7.7
50-60	17610	19440	1590	2640	893	1610	2480	2210	370	318	1900	2730	280	187	510	454	854	872	80	216	1.60	2.73	11.4	7.3
	19760	17450	1550	4790	657	1530	1710	2630	274	273	1620	1980	283	109	458	496	765	764	112	108	1.72	1.60	3.7	5.0
	18310	20520	3140	2920	717	1570	1960	2900	363	270	1600	4840	191	86	586	433	821	681	84	62	0.92	0.84	8.3	10.6
	10880	*20610*	*2050*	*1920*	*1040*	*1020*	*3750*	*1390*	322	*288*	*2930*	*1410*	325	335	725	656	*1153*	*1140*	*87*	*79*	*1.20*	*1.21*	*38.0*	*8.5*
	24180	14550	2250	1590	647	1330	2770	2890	183	295	2080	3200	233	453	709	576	834	840	88	76	1.51	1.25	7.6	20.9
	22640	15540	2510	2460	651	1320	1810	2230	228	320	1890	4460	324	624	634	632	766	979	102	81	0.99	0.90	6.9	65.7
	19620	14410	5940	4580	1120	1420	3000	4070	471	570	1080	3030	338	158	775	548	1104	925	244	255	1.86	1.41	5.3	5.1
0-10/30-40																								
tt	0.001	0.001	0.114	0.030	0.025	0.002	0.532	0.001	0.09	0.09	0.107	0.000	0.481	0.089	0.000	0.000	0.000	0.000	0.94	0.36	0.00	0.27	0.00	0.00
tinv-6	6.349	6.519	1.846	2.823	2.971	5.217	0.664	6.098	2.00	2.00	1.894	7.409	0.750	2.027	7.008	12.144	8.252	9.537	0.08	1.00	4.46	1.22	14.45	14.90
%	>99%	>99%	>80%	>95%	>95%	>99%	NS	>99%	>90%	>90%	>80%	>99%	>50%	>90%	>99%	>99%	>99%	>99%	NS	>60%	>99%	>70%	>99%	>99%
30-40/50-60																								
tt	0.905	0.591	0.652	0.957	0.464	0.135	0.195	0.098	0.40	0.63	0.436	0.642	0.264	0.926	0.925	0.851	0.151	0.718	0.14	0.88	0.93	0.68	0.716	0.472
tinv-6	0.125	0.568	0.474	0.057	0.782	1.729	1.460	1.961	0.91	0.50	0.834	0.490	1.233	0.097	0.099	0.196	1.645	0.378	1.69	0.15	0.09	0.44	0.381	0.767
%	NS	NS	NS	NS	>50%	>80%	>80%	>90%	>60%	NS	>50%	NS	>70%	NS	NS	NS	>80%	NS	>80%	NS	NS	NS	NS	>50%
0-10/50-60																								
tt	0.008	0.034	0.204	0.010	0.108	0.000	0.179	0.798	0.25	0.10	0.008	0.002	0.090	0.128	0.000	0.001	0.001	0.003	0.45	0.38	0.00	0.50	0.00	0.00
tinv-5	3.913	2.734	1.426	3.725	1.886	7.241	1.520	0.267	1.27	1.92	3.900	5.284	2.016	1.763	6.945	6.589	6.098	4.745	0.80	0.95	4.52	0.72	10.58	7.51
%	>98%	>95%	>70%	>98%	>80%		>80%	NS	>70%	>80%	>98%	>99%	>90%	>80%	>70%	>99%	>99%	>99%	>50%	>60%	>99%	NS	>99%	>99%

tt=Student t-test, tinv= inverse of t-test, %=significant difference, NS=not significant

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-1: Ca:Al, Ca:Mg, Ca:K Ratios at 0-10 cm depth.

	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
	Ca	Al	Ca/Al	Ca	Al	Ca/Al	Ca	Mg	Ca/Mg	Ca	Mg	CA/Mg	Ca	K	Ca/K	Ca	K	Ca/K
Spring 1999	12520	4540	2.758	17890	2930	6.106	12520	2330	5.373	17890	2760	6.482	12520	1520	8.237	17890	1000	17.890
	2810	6180	0.456	5910	3980	1.485	2810	849	3.310	5910	2200	2.686	2810	1140	2.465	5910	857	6.896
	2820	6410	0.440	8890	5120	1.736	2820	943	2.990	8890	3450	2.577	2820	1260	2.238	8890	1180	7.534
	1980	5150	0.384	7890	6300	1.252	1980	532	3.722	7890	2660	2.966	1980	1010	1.960	7890	1560	5.058
	1930	4310	0.448	9390	2370	3.962	1930	826	2.337	9390	1820	5.159	1930	1590	1.214	9390	361	26.011
	2690	888	3.029	8370	6910	1.211	2690	970	2.773	8370	1710	4.895	2690	2220	1.212	8370	1510	5.543
Fall 1999	2910	4350	0.669				2910	840	3.464				2910	1150	2.530			
	4770	2250	2.120	7560	2670	2.831	4770	530	9.000	7560	2730	2.769	4770	313	15.240	7560	3110	2.431
	907	5620	0.161	5590	8010	0.698	907	499	1.818	5590	1930	2.896	907	1200	0.756	5590	1810	3.088
	2870	9090	0.316	2620	7680	0.341	2870	692	4.147	2620	1280	2.047	2870	1420	2.021	2620	1960	1.337
	3240	8450	0.383	4930	7370	0.669	3240	775	4.181	4930	2220	2.221	3240	1390	2.331	4930	1620	3.043
	1350	7650	0.176	5820	5690	1.023	1350	651	2.074	5820	2690	2.164	1350	1500	0.900	5820	2380	2.445
Spring 2000	3520	7810	0.451	8890	6180	1.439	3520	947	3.717	8890	2410	3.689	3520	1760	2.000	8890	1600	5.556
	1870	5330	0.351	8800	8140	1.081	1870	777	2.407	8800	1560	5.641	1870	1930	0.969	8800	1690	5.207
	4040	2350	1.719	3040	10110	0.301	4040	939	4.302	3040	1840	1.652	4040	1230	3.285	3040	2600	1.169
	2350	6070	0.387	7660	9870	0.776	2350	492	4.776	7660	1690	4.533	2350	875	2.686	7660	1350	5.674
	3670	7330	0.501	3910	12980	0.301	3670	851	4.313	3910	1810	2.160	3670	1170	3.137	3910	2040	1.917
	4210	9660	0.436	6180	11990	0.515	4210	959	4.390	6180	2090	2.957	4210	1610	2.615	6180	2000	3.090
Fall 2000	13420	10250	1.309	5300	14500	0.366	13420	2430	5.523	5300	1980	2.677	13420	2050	6.546	5300	2770	1.913
	5620	15300	0.367	8180	12030	0.680	5620	1630	3.448	8180	1920	4.260	5620	2290	2.454	8180	1900	4.306
	2490	11010	0.226	9550	7850	1.217	2490	803	3.101	9550	1700	5.618	2490	1790	1.391	9550	2230	4.283
	2910	10010	0.291	3860	9900	0.390	2910	974	2.988	3860	1480	2.608	2910	3500	0.831	3860	2880	1.340
	2300	10650	0.216	4110	16600	0.248	2300	695	3.309	4110	1700	2.418	2300	1290	1.783	4110	2800	1.468
	5070	2690	1.885	4040	13880	0.291	5070	914	5.547	4040	1510	2.675	5070	1160	4.371	4040	2700	1.496
	4400	5610	0.784	5050	11030	0.458	4400	1260	3.492	5050	1800	2.806	4400	2920	1.507	5050	3610	1.399
Average	3867	6768	0.811	6810	8504	1.224	3867	964	3.860	6810	2039	3.356	3867	1572	2.987	6810	1980	6.004
tt						0.126						0.246						0.141
tinv-23						1.589						1.189						1.624
% SD	0-10 cm				Ca/Al	>80%					CA/Mg	>70%					Ca/K	>80%

% = % Significant difference, NS = No significant difference, t-test = Student t-test, t-inv-# = Number of samples used in statisical calculations

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-2: Ca:Na, Ca:Fe, Ca:Mn Ratios at 0-10 cm depth

	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
	Ca	Na	Ca/Na	Ca	Na	Ca/Na	Ca	Fe	Ca/Fe	Ca	Fe	Ca/Fe	Ca	Mn	Ca/Mn	Ca	Mn	Ca/Mn
Spring 1999	12520	661	18.941	17890	514	34.805	12520	2500	5.008	17890	2410	7.423	12520	361	34.681	17890	471	37.983
	2810	125	22.480	5910	126	46.905	2810	5320	0.528	5910	6610	0.894	2810	646	4.350	5910	808	7.314
	2820	105	26.857	8890	188	47.287	2820	4600	0.613	8890	6420	1.385	2820	810	3.481	8890	675	13.170
	1980	105	18.867	7890	257	30.700	1980	8810	0.225	7890	4290	1.839	1980	503	3.936	7890	928	8.502
	1930	156	12.372	9390	105	89.429	1930	3520	0.548	9390	1300	7.223	1930	271	7.122	9390	252	37.262
	2690	111	24.234	8370	186	45.000	2690	314	8.567	8370	4090	2.046	2690	460	5.848	8370	162	51.667
Fall 1999	2910	152	19.145				2910	3340	0.871				2910	337	8.635			
	4770	79	60.380	7560	509	14.853	4770	1640	2.909	7560	1560	4.846	4770	163	29.264	7560	222	34.054
	907	90	10.078	5590	204	27.402	907	3500	0.259	5590	5250	1.065	907	189	4.799	5590	466	11.996
	2870	288	9.965	2620	154	17.013	2870	5220	0.550	2620	5390	0.486	2870	363	7.906	2620	261	10.038
	3240	219	14.795	4930	127	38.819	3240	4430	0.731	4930	7110	0.693	3240	554	5.848	4930	1450	3.400
	1350	143	9.441	5820	246	23.659	1350	4060	0.333	5820	2870	2.028	1350	196	6.888	5820	709	8.209
Spring 2000	3520	169	20.828	8890	281	31.637	3520	3090	1.139	8890	2980	2.983	3520	929	3.789	8890	571	15.569
	1870	353	5.297	8800	296	29.730	1870	3290	0.568	8800	6350	1.386	1870	264	7.083	8800	1070	8.224
	4040	250	16.160	3040	316	9.620	4040	1150	3.513	3040	5530	0.550	4040	449	8.998	3040	431	7.053
	2350	161	14.596	7660	382	20.052	2350	2900	0.810	7660	4180	1.833	2350	458	5.131	7660	363	21.102
	3670	223	16.457	3910	204	19.167	3670	6200	0.592	3910	8460	0.462	3670	147	24.966	3910	563	6.945
	4210	576	7.309	6180	254	24.331	4210	4540	0.927	6180	6730	0.918	4210	726	5.799	6180	742	8.329
Fall 2000	13420	415	32.337	5300	320	16.563	13420	7670	1.750	5300	8080	0.656	13420	911	14.731	5300	347	15.274
	5620	299	18.796	8180	267	30.637	5620	7310	0.769	8180	6500	1.258	5620	633	8.878	8180	433	18.891
	2490	243	10.247	9550	627	15.231	2490	6520	0.382	9550	5520	1.730	2490	232	10.733	9550	1720	5.552
	2910	400	7.275	3860	430	8.977	2910	5690	0.511	3860	6420	0.601	2910	544	5.349	3860	669	5.770
	2300	185	12.432	4110	303	13.564	2300	4420	0.520	4110	10630	0.387	2300	189	12.169	4110	587	7.002
	5070	351	14.444	4040	397	10.176	5070	1740	2.914	4040	7090	0.570	5070	207	24.493	4040	507	7.968
	4400	609	7.225	5050	640	7.891	4400	2820	1.560	5050	7250	0.697	4400	644	6.832	5050	359	14.067
Average	3867	259	17.238	6810	306	27.227	3867	4184	1.484	6810	5543	1.832	3867	447	10.468	6810	615	15.223
tt						0.027						0.504						0.092
tinv-23						2.358						0.679						1.757
% SD	0-10 cm				Ca/Na	>95%					Ca/Fe	NS					Ca/Mn	>90%

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-3: Ca:P, Ca:S, Ca:Zn Ratios at 0-10 cm depth

	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
	Ca	P	Ca/P	Ca	P	CA/P	Ca	S	Ca/S	Ca	S	Ca/S	Ca	Zn	CA/Zn	Ca	Zn	Ca/Zn
Spring 1999	12520	1023	12.239	17890	820	21.817	12520	1472	8.505	17890	1470	12.170	12520	181	69	17890	421	42
	2810	676	4.157	5910	580	10.190	2810	1083	2.595	5910	1089	5.427	2810	60	47	5910	49	121
	2820	747	3.775	8890	542	16.402	2820	984	2.866	8890	1101	8.074	2820	67	42	8890	57	156
	1980	1074	1.844	7890	746	10.576	1980	1171	1.691	7890	1422	5.549	1980	65	30	7890	133	59
	1930	711	2.714	9390	421	22.304	1930	1104	1.748	9390	845	11.112	1930	49	39	9390	260	36
	2690	599	4.491	8370	773	10.828	2690	1044	2.577	8370	1160	7.216	2690	30	90	8370	638	13
Fall 1999	2910	737	3.948				2910	1051	2.769				2910	101	29			
	4770	527	9.051	7560	618	12.233	4770	846	5.638	7560	1420	5.324	4770	225	21	7560	282	27
	907	633	1.433	5590	713	7.840	907	1197	0.758	5590	1377	4.060	907	46	20	5590	115	49
	2870	1260	2.278	2620	760	3.447	2870	1219	2.354	2620	1233	2.126	2870	136	21	2620	76	34
	3240	833	3.890	4930	659	7.481	3240	1152	2.813	4930	1011	4.876	3240	77	42	4930	55	90
	1350	763	1.769	5820	647	8.995	1350	1067	1.265	5820	1177	4.945	1350	42	32	5820	74	79
Spring 2000	3520	923	3.814	8890	721	12.330	3520	1256	2.803	8890	1045	8.507	3520	102	35	8890	193	46
	1870	1042	1.795	8800	968	9.091	1870	1396	1.340	8800	1325	6.642	1870	74	25	8800	396	22
	4040	767	5.267	3040	826	3.680	4040	1159	3.486	3040	1116	2.724	4040	206	20	3040	114	27
	2350	858	2.739	7660	791	9.684	2350	1216	1.933	7660	1142	6.708	2350	136	17	7660	341	22
	3670	1055	3.479	3910	870	4.494	3670	1467	2.502	3910	1094	3.574	3670	98	37	3910	91	43
	4210	1203	3.500	6180	774	7.984	4210	1746	2.411	6180	1240	4.984	4210	75	56	6180	90	69
Fall 2000	13420	907	14.796	5300	887	5.975	13420	2138	6.277	5300	1426	3.717	13420	336	40	5300	205	26
	5620	935	6.011	8180	842	9.716	5620	1690	3.325	8180	1529	5.350	5620	161	35	8180	137	60
	2490	928	2.683	9550	1136	8.407	2490	1652	1.507	9550	1463	6.528	2490	98	25	9550	126	76
	2910	1118	2.603	3860	973	3.967	2910	1437	2.025	3860	1323	2.918	2910	124	23	3860	150	26
	2300	1102	2.087	4110	983	4.181	2300	1553	1.481	4110	1222	3.363	2300	78	29	4110	147	28
	5070	705	7.191	4040	808	5.000	5070	1467	3.456	4040	1095	3.689	5070	108	47	4040	98	41
	4400	1085	4.055	5050	949	5.321	4400	1567	2.808	5050	1413	3.574	4400	129	34	5050	162	31
Average	3867	888	4.464	6810	784	9.248	3867	1325	2.837	6810	1239	5.548	3867	112	36	6810	184	61
tt						0.000						0.000						0.065
tinv-23						4.241						5.057						1.938
% SD	0-10 cm				Ca/P	>99%					Ca/S	>99%					Ca/Zn	>90%

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-4: Ca:Cd, Ca:Pb Ratios at 0-10 cm depth

	Unlimed			Limed			Unlimed			Limed		
	Ca	Cd	Ca/Cd	Ca	Cd	Ca/Cd	Ca	Pb	Ca/Pb	Ca	Pb	Ca/Pb
Spring 1999	12520	1.07	11701	17890	0.71	25197	12520	55.3	226	17890	73.0	245
	2810	0.58	4845	5910	0.56	10554	2810	70.7	40	5910	79.7	74
	2820	0.58	4862	8890	0.37	24027	2820	94.1	30	8890	66.2	134
	1980	0.39	5077	7890	1.13	6982	1980	120.0	17	7890	109.0	72
	1930	0.47	4106	9390	0.66	14227	1930	82.2	23	9390	39.8	236
	2690	0.59	4559	8370	1.07	7822	2690	28.7	94	8370	74.6	112
Fall 1999	2910	0.51	5706				2910	63.0	46			
	4770	0.64	7453	7560	1.03	7340	4770	32.9	145	7560	50.5	150
	907	0.32	2834	5590	0.49	11408	907	74.0	12	5590	69.7	80
	2870	0.47	6106	2620	0.94	2787	2870	102.5	28	2620	107.8	24
	3240	0.62	5226	4930	0.57	8649	3240	96.6	34	4930	73.4	67
	1350	0.33	4091	5820	0.63	9238	1350	88.2	15	5820	55.6	105
Spring 2000	3520	0.93	3785	8890	0.84	10583	3520	78.5	45	8890	68.6	130
	1870	1.14	1640	8800	1.33	6617	1870	144.6	13	8800	126.0	70
	4040	0.84	4810	3040	2.02	1505	4040	97.3	42	3040	87.0	35
	2350	0.70	3357	7660	1.11	6901	2350	102.0	23	7660	100.3	76
	3670	0.47	7809	3910	0.59	6627	3670	165.5	22	3910	97.0	40
	4210	0.40	10526	6180	0.53	11660	4210	116.9	36	6180	118.7	52
Fall 2000	13420	1.23	10911	5300	0.69	7681	13420	112.5	119	5300	95.7	55
	5620	0.35	16057	8180	0.62	13194	5620	111.1	51	8180	104.9	78
	2490	0.25	9960	9550	1.00	9550	2490	145.4	17	9550	127.9	75
	2910	0.62	4694	3860	1.72	2244	2910	126.2	23	3860	94.4	41
	2300	0.28	8214	4110	1.00	4110	2300	100.3	23	4110	140.0	29
	5070	0.81	6259	4040	0.93	4344	5070	161.5	31	4040	90.3	45
	4400	1.10	4000	5050	2.15	2349	4400	85.8	51	5050	113.1	45
Average	3867	0.63	6343	6810	0.95	8983	3867	98.2	48	6810	90.1	86
tt						0.041						0.002
tinv-23						2.167						3.556
% SD	0-10 cm				Ca/Cd	>95%					Ca/Pb	>99%

% = % Significant difference, NS = No significant difference, t-test = Student t-test, t-inv-# = Number of samples used in statisical calculations

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-5: Ca:Al, Ca:Mg, Ca:K Ratios at 30-40 cm depth.

	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
	Ca	Al	Ca/Al	Ca	Al	Ca/Al	Ca	Mg	Ca/Mg	Ca	Mg	CA/Mg	Ca	K	Ca/K	Ca	K	Ca/K
Spring 1999	5000	12310	0.406				5000	999	5.005				5000	1870	2.674			
	8900	10140	0.878	9750	17920	0.544	8900	1630	5.460	9750	2420	4.029	8900	1220	7.295	9750	2100	4.643
	7840	10340	0.758	11870	13800	0.860	7840	1110	7.063	11870	2270	5.229	7840	1180	6.644	11870	2120	5.599
	2320	16230	0.143	7180	15200	0.472	2320	569	4.077	7180	2140	3.355	2320	990	2.343	7180	1420	5.056
	4820	8100	0.595	5230	12390	0.422	4820	1060	4.547	5230	1590	3.289	4820	610	7.902	5230	726	7.204
	3860	3220	1.199	6840	10260	0.667	3860	1020	3.784	6840	1090	6.275	3860	2550	1.514	6840	1170	5.846
Fall 1999	3990	12770	0.312	2790	12010	0.232	3990	967	4.126	2790	1740	1.603	3990	1970	2.025	2790	1690	1.651
	7320	16260	0.450	2690	16830	0.160	7320	1450	5.048	2690	1470	1.830	7320	1670	4.383	2690	1790	1.503
	1530	15240	0.100	2320	18460	0.126	1530	838	1.826	2320	1580	1.468	1530	2150	0.712	2320	1790	1.296
	4280	18430	0.232	13310	3050	4.364	4280	729	5.871	13310	1790	7.436	4280	1270	3.370	13310	873	15.246
	3520	16730	0.210	2750	15970	0.172	3520	704	5.000	2750	1700	1.618	3520	1950	1.805	2750	2270	1.211
	2190	16730	0.131	3460	16770	0.206	2190	463	4.730	3460	1450	2.386	2190	1450	1.510	3460	1750	1.977
Spring 2000	1360	21270	0.064	1370	18780	0.073	1360	630	2.159	1370	1540	0.890	1360	1950	0.697	1370	1430	0.958
	4190	3230	1.297	2980	16910	0.176	4190	871	4.811	2980	1290	2.310	4190	2480	1.690	2980	1730	1.723
	1820	21400	0.085	2590	21190	0.122	1820	568	3.204	2590	1550	1.671	1820	1100	1.655	2590	1210	2.140
	2710	18000	0.151	2830	20240	0.140	2710	719	3.769	2830	1540	1.838	2710	873	3.104	2830	1150	2.461
	697	17350	0.040	2100	12880	0.163	697	764	0.912	2100	1360	1.544	697	3230	0.216	2100	2700	0.778
	2640	17610	0.150	1820	20390	0.089	2640	697	3.788	1820	1370	1.328	2640	1360	1.941	1820	1410	1.291
Fall 2000	4600	15180	0.303	2980	17600	0.169	4600	1180	3.898	2980	1160	2.569	4600	2200	2.091	2980	1880	1.585
	2980	21960	0.136	3070	17900	0.172	2980	651	4.578	3070	1010	3.040	2980	1840	1.620	3070	1690	1.817
	2490	20480	0.122	2130	16490	0.129	2490	717	3.473	2130	1140	1.868	2490	2210	1.127	2130	1180	1.805
	2370	26420	0.090	2880	19660	0.146	2370	558	4.247	2880	1240	2.323	2370	1180	2.008	2880	2110	1.365
	1930	18400	0.105	2910	21510	0.135	1930	488	3.955	2910	1340	2.172	1930	999	1.932	2910	2000	1.455
	3300	10220	0.323	1850	17640	0.105	3300	686	4.810	1850	1180	1.568	3300	1940	1.701	1850	2340	0.791
	3510	17490	0.201	4920	17090	0.288	3510	957	3.668	4920	1430	3.441	3510	2870	1.223	4920	2690	1.829
Average	3607	16420	0.339	4276	16289	0.422	3607	841	4.152	4276	1616	2.712	3607	1724	2.627	4276	1717	2.968
t-test						0.647						0.000						0.447
tinv-23						0.464						4.810						0.773
% SD	30-40 cm				Ca/Al	NS					CA/Mg	>99%					Ca/K	>50%

% = % Significant difference, NS = No significant difference, t-test = Student t-test, t-inv-# = Number of samples used in statisical calculations

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-6: Ca:Na, Ca:Fe, Ca:Mn Ratios at 30-40 cm depth

	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
	Ca	Na	Ca/Na	Ca	Na	Ca/Na	Ca	Fe	Ca/Fe	Ca	Fe	Ca/Fe	Ca	Mn	Ca/Mn	Ca	Mn	Ca/Mn
Spring 1999	5000	308	16.234				5000	886	5.643				5000	345	14.493			
	8900	248	35.887	9750	875	11.143	8900	1010	8.812	9750	1400	6.964	8900	417	21.343	9750	426	22.887
	7840	290	27.034	11870	507	23.412	7840	763	10.275	11870	1950	6.087	7840	596	13.154	11870	529	22.439
	2320	102	22.745	7180	431	16.659	2320	1550	1.497	7180	1160	6.190	2320	1100	2.109	7180	285	25.193
	4820	133	36.241	5230	139	37.626	4820	647	7.450	5230	1350	3.874	4820	818	5.892	5230	419	12.482
	3860	209	18.469	6840	161	42.484	3860	1880	2.053	6840	501	13.653	3860	122	31.639	6840	591	11.574
Fall 1999	3990	287	13.902	2790	200	13.950	3990	1600	2.494	2790	1500	1.860	3990	369	10.813	2790	249	11.205
	7320	912	8.026	2690	174	15.460	7320	1230	5.951	2690	2760	0.975	7320	406	18.030	2690	209	12.871
	1530	106	14.434	2320	206	11.262	1530	2630	0.582	2320	4130	0.562	1530	505	3.030	2320	276	8.406
	4280	138	31.014	13310	209	63.684	4280	3100	1.381	13310	1690	7.876	4280	426	10.047	13310	437	30.458
	3520	144	24.444	2750	167	16.467	3520	2360	1.492	2750	3160	0.870	3520	453	7.770	2750	814	3.378
	2190	83	26.386	3460	215	16.093	2190	2610	0.839	3460	3850	0.899	2190	376	5.824	3460	863	4.009
Spring 2000	1360	314	4.331	1370	197	6.954	1360	2160	0.630	1370	1970	0.695	1360	863	1.576	1370	325	4.215
	4190	276	15.181	2980	222	13.423	4190	1380	3.036	2980	1810	1.646	4190	295	14.203	2980	481	6.195
	1820	178	10.225	2590	165	15.697	1820	1290	1.411	2590	1340	1.933	1820	351	5.185	2590	270	9.593
	2710	185	14.649	2830	142	19.930	2710	872	3.108	2830	1920	1.474	2710	697	3.888	2830	998	2.836
	697	181	3.851	2100	170	12.353	697	1870	0.373	2100	1960	1.071	697	262	2.660	2100	289	7.266
	2640	189	13.968	1820	334	5.449	2640	1010	2.614	1820	2630	0.692	2640	524	5.038	1820	675	2.696
Fall 2000	4600	311	14.791	2980	243	12.263	4600	2110	2.180	2980	1640	1.817	4600	716	6.425	2980	258	11.550
	2980	244	12.213	3070	222	13.829	2980	972	3.066	3070	1680	1.827	2980	274	10.876	3070	206	14.903
	2490	300	8.300	2130	239	8.912	2490	2700	0.922	2130	3320	0.642	2490	300	8.300	2130	213	10.000
	2370	225	10.533	2880	431	6.682	2370	1960	1.209	2880	2500	1.152	2370	272	8.713	2880	438	6.575
	1930	151	12.781	2910	339	8.584	1930	1180	1.636	2910	4710	0.618	1930	655	2.947	2910	160	18.188
	3300	365	9.041	1850	309	5.987	3300	6550	0.504	1850	4370	0.423	3300	53	62.264	1850	361	5.125
	3510	433	8.106	4920	431	11.415	3510	1970	1.782	4920	1940	2.536	3510	544	6.452	4920	268	18.358
Average	3607	252	16.512	4276	280	17.072	3607	1852	2.838	4276	2302	2.764	3607	470	11.307	4276	418	11.767
t-test						0.810						0.951						0.851
tinv-23						0.243						0.062						0.190
% SD	30-40 cm				Ca/Na	NS					Ca/Fe	NS					Ca/Mn	NS

% = % Significant difference, NS = No significant difference, t-test = Student t-test, t-inv-# = Number of samples used in statisical calculations

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-7: Ca:P, Ca:S, Ca:Zn Ratios at 30-40 cm depth

	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
	Ca	P	Ca/P	Ca	P	CA/P	Ca	S	Ca/S	Ca	S	Ca/S	Ca	Zn	CA/Zn	Ca	Zn	Ca/Zn
Spring 1999	5000	919	0.562				5000	1152	4.340				5000	404	12			
	8900	505	17.624	9750	958	10.177	8900	725	12.276	9750	1380	7.065	8900	220	40	9750	502	19
	7840	504	15.556	11870	553	21.465	7840	738	10.623	11870	873	13.597	7840	278	28	11870	598	20
	2320	779	2.978	7180	676	10.621	2320	715	3.245	7180	1760	4.080	2320	182	13	7180	309	23
	4820	563	8.561	5230	504	10.377	4820	732	6.585	5230	948	5.517	4820	293	16	5230	298	18
	3860	601	6.423	6840	1236	5.534	3860	842	4.584	6840	923	7.411	3860	86	45	6840	192	36
Fall 1999	3990	627	6.364	2790	606	4.604	3990	933	4.277	2790	693	4.026	3990	195	20	2790	220	13
	7320	463	15.810	2690	481	5.593	7320	1816	4.031	2690	688	3.910	7320	166	44	2690	107	25
	1530	546	2.802	2320	461	5.033	1530	658	2.325	2320	631	3.677	1530	123	12	2320	137	17
	4280	544	7.868	13310	617	21.572	4280	681	6.285	13310	888	14.989	4280	107	40	13310	325	41
	3520	785	4.484	2750	525	5.238	3520	769	4.577	2750	661	4.160	3520	169	21	2750	76	36
	2190	544	4.026	3460	554	6.245	2190	735	2.980	3460	789	4.385	2190	187	12	3460	80	43
Spring 2000	1360	711	1.913	1370	566	2.420	1360	744	1.828	1370	854	1.604	1360	130	10	1370	109	13
	4190	638	6.567	2980	624	4.776	4190	992	4.224	2980	869	3.429	4190	182	23	2980	163	18
	1820	600	3.033	2590	592	4.375	1820	701	2.596	2590	746	3.472	1820	122	15	2590	133	19
	2710	696	3.894	2830	676	4.186	2710	828	3.273	2830	912	3.103	2710	119	23	2830	83	34
	697	556	1.254	2100	407	5.160	697	757	0.921	2100	662	3.172	697	61	11	2100	58	36
	2640	546	4.835	1820	590	3.085	2640	789	3.346	1820	843	2.159	2640	115	23	1820	76	24
Fall 2000	4600	550	8.364	2980	476	6.261	4600	894	5.145	2980	790	3.772	4600	115	40	2980	242	12
	2980	578	5.156	3070	549	5.592	2980	758	3.931	3070	790	3.886	2980	191	16	3070	90	34
	2490	585	4.256	2130	594	3.586	2490	783	3.180	2130	1101	1.935	2490	122	20	2130	48	44
	2370	835	2.838	2880	628	4.586	2370	972	2.438	2880	944	3.051	2370	83	29	2880	161	18
	1930	596	3.238	2910	547	5.320	1930	757	2.550	2910	756	3.849	1930	133	15	2910	69	42
	3300	601	5.491	1850	426	4.343	3300	799	4.130	1850	666	2.778	3300	180	18	1850	92	20
	3510	625	5.616	4920	635	7.748	3510	971	3.615	4920	923	5.330	3510	187	19	4920	193	25
Average	3607	620	5.980	4276	603	6.996	3607	850	4.292	4276	879	4.765	3607	166	23	4276	182	26
t-test						0.409						0.353						0.316
tinv-23						0.842						0.948						1.025
% SD	30-40 cm				CA/P	>50%					Ca/S	>60%					Ca/Zn	>60%

% = % Significant difference, NS = No significant difference, t-test = Student t-test, t-inv-# = Number of samples used in statisical calculations

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-8: Ca:Cd, Ca:Pb Ratios at 30-40 cm depth

	Unlimed			Limed			Unlimed			Limed		
	Ca	Cd	Ca/Cd	Ca	Cd	Ca/Cd	Ca	Pb	Ca/Pb	Ca	Pb	Ca/Pb
Spring 1999	5000	2.70	1852				5000	24.5	204			
	8900	0.93	9570	9750	3.79	2573	8900	21.9	406	9750	31.7	308
	7840	1.20	6533	11870	2.30	5161	7840	19.3	406	11870	16.4	724
	2320	2.11	1100	7180	1.29	5566	2320	10.7	217	7180	16.0	449
	4820	1.93	2497	5230	0.74	7068	4820	6.7	719	5230	12.7	412
	3860	0.64	6031	6840	1.18	5797	3860	26.8	144	6840	8.0	855
Fall 1999	3990	1.81	2204	2790	1.03	2709	3990	12.6	317	2790	17.0	164
	7320	0.82	8927	2690	1.03	2612	7320	4.4	1664	2690	10.3	261
	1530	1.85	827	2320	1.60	1450	1530	10.8	142	2320	16.1	144
	4280	1.18	3627	13310	0.63	21127	4280	13.8	310	13310	34.6	385
	3520	2.11	1668	2750	0.72	3819	3520	8.1	435	2750	10.1	272
	2190	2.05	1068	3460	0.94	3681	2190	8.8	249	3460	19.4	178
Spring 2000	1360	1.32	1030	1370	1.97	695	1360	11.0	124	1370	18.8	73
	4190	0.76	5513	2980	1.76	1693	4190	66.2	63	2980	25.0	119
	1820	1.08	1685	2590	1.41	1837	1820	31.5	58	2590	4.9	529
	2710	1.48	1831	2830	1.10	2573	2710	11.7	232	2830	27.1	104
	697	0.58	1202	2100	1.04	2019	697	7.2	97	2100	8.2	256
	2640	1.72	1535	1820	1.63	1117	2640	7.3	362	1820	11.8	154
Fall 2000	4600	1.28	3594	2980	2.02	1475	4600	11.4	404	2980	8.4	355
	2980	1.20	2483	3070	1.70	1806	2980	5.5	542	3070	12.4	248
	2490	1.71	1456	2130	0.73	2918	2490	7.5	332	2130	14.5	147
	2370	1.35	1756	2880	2.42	1190	2370	14.3	166	2880	13.1	220
	1930	1.20	1608	2910	1.26	2310	1930	7.4	261	2910	12.2	239
	3300	1.18	2797	1850	1.29	1434	3300	43.4	76	1850	7.9	234
	3510	1.98	1773	4920	1.21	4066	3510	9.5	369	4920	7.7	639
Average	3607	1.46	2867	4276	1.45	3612	3607	16.1	332	4276	15	311
t-test						0.524						0.740
tinv-23						0.648						0.336
% SD	30-40 cm				Ca/Cd	NS					Ca/Pb	NS

% = % Significant difference, NS = No significant difference, t-test = Student t-test, t-inv-# = Number of samples used in statisical calculations

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-9: Ca:Al, Ca:Mg, Ca:K Ratios at 50-60 cm depth.

	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
	Ca	Al	Ca/Al	Ca	Al	Ca/Al	Ca	Mg	Ca/Mg	Ca	Mg	CA/Mg	Ca	K	Ca/K	Ca	K	Ca/K
Spring 1999	8560	14920	0.574	8670	11910	0.728	8560	1250	6.848	8670	1870	4.636	8560	1460	5.863	8670	1440	6.021
	5580	10210	0.547	9150	8040	1.138	5580	1120	4.982	9150	1950	4.692	5580	789	7.072	9150	1730	5.289
	5040	12160	0.414	4920	12880	0.382	5040	816	6.176	4920	1530	3.216	5040	721	6.990	4920	1500	3.280
	4860	13390	0.363	6200	16270	0.381	4860	806	6.030	6200	1280	4.844	4860	910	5.341	6200	1580	3.924
	3350	13550	0.247	3860	12040	0.321	3350	515	6.505	3860	957	4.033	3350	1170	2.863	3860	1330	2.902
	2920	15850	0.184	3260	11790	0.277	2920	699	4.177	3260	1300	2.508	2920	2430	1.202	3260	1810	1.801
Fall 1999	2840	11800					2840	879					2840	1990				
	5700	9370	0.608	3660	8780	0.417	5700	1250	4.560	3660	1170	3.128	5700	1517	3.757	3660	1030	3.553
	1760	14880	0.118	3490	11300	0.309	1760	1040	1.692	3490	1690	2.065	1760	1560	1.128	3490	1550	2.252
	6120	10980	0.557	3690	16460	0.224	6120	1240	4.935	3690	1530	2.412	6120	811	7.546	3690	1890	1.952
	3900	16690	0.234	2340	14020	0.167	3900	814	4.791	2340	1520	1.539	3900	2290	1.703	2340	1980	1.182
Spring 2000	1570	18080	0.087	1290	19130	0.067	1570	627	2.504	1290	1220	1.057	1570	3520	0.446	1290	2370	0.544
	1310	14670	0.089	1470	15890	0.093	1310	458	2.860	1470	835	1.760	1310	1560	0.840	1470	1750	0.840
	570	9010	0.063	4190	20880	0.201	570	770	0.740	4190	898	4.666	570	2720	0.210	4190	1110	3.775
	1190	20500	0.058	1900	14670	0.130	1190	549	2.168	1900	1380	1.377	1190	1840	0.647	1900	2630	0.722
	2280	13570	0.168	1660	18840	0.088	2280	808	2.822	1660	866	1.917	2280	1900	1.200	1660	1260	1.317
	514	21110	0.024	1100	14640	0.075	514	588	0.874	1100	1050	1.048	514	1800	0.286	1100	4610	0.239
Fall 2000	1590	17610	0.090	2640	19440	0.136	1590	893	1.781	2640	1610	1.640	1590	2480	0.641	2640	2210	1.195
	1550	19760	0.078	4790	17450	0.274	1550	657	2.359	4790	1530	3.131	1550	1710	0.906	4790	2630	1.821
	3140	18310	0.171	2920	20520	0.142	3140	717	4.379	2920	1570	1.860	3140	1960	1.602	2920	2900	1.007
	2050	10880	0.188	1920	20610	0.093	2050	1040	1.971	1920	1020	1.882	2050	3750	0.547	1920	1390	1.381
	2250	24180	0.093	1590	14550	0.109	2250	647	3.478	1590	1330	1.195	2250	2770	0.812	1590	2890	0.550
	2510	22640	0.111	2460	15540	0.158	2510	651	3.856	2460	1320	1.864	2510	1810	1.387	2460	2230	1.103
	5940	19620	0.303	4580	14410	0.318	5940	1120	5.304	4580	1420	3.225	5940	3030	1.960	4580	4070	1.125
Average	3212	15573	0.234	3554	15220	0.271	3212	831	3.730	3554	1341	2.595	3212	1937	2.389	3554	2082	2.077
t-test						0.304						0.002						0.396
tinv-22						1.052						3.466						0.865
% SD	50-60 cm				Ca/Al	>60%					CA/Mg	>99%					Ca/K	>60%

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-10: Ca:Na, Ca:Fe, Ca:Mn Ratios at 50-60 cm depth

	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
	Ca	Na	Ca/Na	Ca	Na	Ca/Na	Ca	Fe	Ca/Fe	Ca	Fe	Ca/Fe	Ca	Mn	Ca/Mn	Ca	Mn	Ca/Mn
Spring 1999	8560	349	24.527	8670	325	26.677	8560	1080	7.926	8670	2250	3.853	8560	424	20.189	8670	262	33.092
	5580	216	25.833	9150	173	52.890	5580	1390	4.014	9150	2060	4.442	5580	543	10.276	9150	633	14.455
	5040	216	23.333	4920	175	28.114	5040	1090	4.624	4920	2620	1.878	5040	466	10.815	4920	279	17.634
	4860	176	27.614	6200	195	31.795	4860	885	5.492	6200	2870	2.160	4860	628	7.739	6200	585	10.598
	3350	149	22.483	3860	246	15.691	3350	2330	1.438	3860	1060	3.642	3350	197	17.005	3860	774	4.987
	2920	296	9.865	3260	147	22.177	2920	991	2.947	3260	746	4.370	2920	111	26.306	3260	350	9.314
Fall 1999	2840	181					2840	1850					2840	291				
	5700	574	9.930	3660	135	27.111	5700	1080	5.278	3660	1080	3.389	5700	359	15.877	3660	170	21.529
	1760	188	9.362	3490	176	19.830	1760	2910	0.605	3490	2620	1.332	1760	412	4.272	3490	103	33.883
	6120	198	30.909	3690	183	20.164	6120	761	8.042	3690	3520	1.048	6120	509	12.024	3690	231	15.974
	3900	184	21.196	2340	214	10.935	3900	2930	1.331	2340	4500	0.520	3900	554	7.040	2340	500	4.680
Spring 2000	1570	130	12.077	1290	187	6.898	1570	870	1.805	1290	2900	0.445	1570	516	3.043	1290	220	5.864
	1310	137	9.562	1470	191	7.696	1310	2450	0.535	1470	1690	0.870	1310	172	7.616	1470	392	3.750
	570	402	1.418	4190	147	28.503	570	3200	0.178	4190	1210	3.463	570	170	3.353	4190	180	23.278
	1190	216	5.509	1900	182	10.440	1190	767	1.551	1900	1770	1.073	1190	786	1.514	1900	781	2.433
	2280	217	10.507	1660	205	8.098	2280	892	2.556	1660	2010	0.826	2280	393	5.802	1660	270	6.148
	514	98	5.245	1100	331	3.323	514	2880	0.178	1100	1730	0.636	514	334	1.539	1100	371	2.965
Fall 2000	1590	370	4.297	2640	318	8.302	1590	1900	0.837	2640	2730	0.967	1590	280	5.679	2640	187	14.118
	1550	274	5.657	4790	273	17.546	1550	1620	0.957	4790	1980	2.419	1550	283	5.477	4790	109	43.945
	3140	363	8.650	2920	270	10.815	3140	1600	1.963	2920	4840	0.603	3140	191	16.440	2920	86	33.953
	2050	322	6.366	1920	288	6.667	2050	2930	0.700	1920	1410	1.362	2050	325	6.308	1920	335	5.731
	2250	183	12.295	1590	295	5.390	2250	2080	1.082	1590	3200	0.497	2250	233	9.657	1590	453	3.510
	2510	228	11.009	2460	320	7.688	2510	1890	1.328	2460	4460	0.552	2510	324	7.747	2460	624	3.942
	5940	471	12.611	4580	570	8.035	5940	1080	5.500	4580	3030	1.512	5940	338	17.574	4580	158	28.987
Average	3212	256	13.489	3554	241	16.730	3212	1727	2.646	3554	2447	1.820	3212	368	9.708	3554	350	14.990
t-test						0.151						0.101						0.055
tinv-22						1.488						1.713						2.031
% SD	50-60 cm				Ca/Na	>80%					Ca/Fe	>80%					Ca/Mn	>90%

% = % Significant difference, NS = No significant difference, t-test = Student t-test, t-inv-# = Number of samples used in statisical calculations

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-11: Ca:P, Ca:S, Ca:Zn Ratios at 50-60 cm depth

	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
	Ca	P	Ca/P	Ca	P	CA/P	Ca	S	Ca/S	Ca	S	Ca/S	Ca	Zn	CA/Zn	Ca	Zn	Ca/Zn
Spring 1999	8560	719	11.906	8670	927	9.353	8560	1725	4.962	8670	1463	5.926	8560	360	24	8670	380	23
	5580	507	11.006	9150	669	13.677	5580	1233	4.526	9150	1093	8.371	5580	106	53	9150	427	21
	5040	484	10.413	4920	434	11.336	5040	840	6.000	4920	515	9.553	5040	134	38	4920	58	85
	4860	621	7.826	6200	645	9.612	4860	681	7.137	6200	618	10.032	4860	332	15	6200	184	34
	3350	468	7.158	3860	852	4.531	3350	510	6.569	3860	720	5.361	3350	73	46	3860	130	30
	2920	579	5.043	3260	628	5.191	2920	834	3.501	3260	658	4.954	2920	115	25	3260	168	19
Fall 1999	2840	588					2840	657					2840	163				
	5700	363	15.702	3660	403	9.082	5700	1015	5.616	3660	500	7.320	5700	124	46	3660	234	16
	1760	506	3.478	3490	498	7.008	1760	629	2.798	3490	847	4.120	1760	160	11	3490	132	26
	6120	457	13.392	3690	451	8.182	6120	646	9.474	3690	632	5.839	6120	173	35	3690	154	24
	3900	752	5.186	2340	392	5.969	3900	678	5.752	2340	596	3.926	3900	170	23	2340	54	43
Spring 2000	1570	558	2.814	1290	553	2.333	1570	864	1.817	1290	704	1.832	1570	84	19	1290	77	17
	1310	571	2.294	1470	469	3.134	1310	753	1.740	1470	662	2.221	1310	156	8	1470	106	14
	570	527	1.082	4190	541	7.745	570	717	0.795	4190	682	6.144	570	125	5	4190	536	8
	1190	638	1.865	1900	481	3.950	1190	741	1.606	1900	678	2.802	1190	74	16	1900	317	6
	2280	626	3.642	1660	525	3.162	2280	740	3.081	1660	661	2.511	2280	119	19	1660	102	16
	514	509	1.010	1100	636	1.730	514	674	0.763	1100	953	1.154	514	65	8	1100	94	12
Fall 2000	1590	510	3.118	2640	454	5.815	1590	854	1.862	2640	872	3.028	1590	80	20	2640	216	12
	1550	458	3.384	4790	496	9.657	1550	765	2.026	4790	764	6.270	1550	112	14	4790	108	44
	3140	586	5.358	2920	433	6.744	3140	821	3.825	2920	681	4.288	3140	84	37	2920	62	47
	2050	725	2.828	1920	656	2.927	2050	1153	1.778	1920	1140	1.684	2050	87	24	1920	79	24
	2250	709	3.173	1590	576	2.760	2250	834	2.698	1590	840	1.893	2250	88	26	1590	76	21
	2510	634	3.959	2460	632	3.892	2510	766	3.277	2460	979	2.513	2510	102	25	2460	81	30
	5940	775	7.665	4580	548	8.358	5940	1104	5.380	4580	925	4.951	5940	244	24	4580	255	18
Average	3212	578	5.796	3554	561	6.354	3212	843	3.782	3554	791	4.639	3212	139	24	3554	175	26
t-test						0.385						0.062						0.712
tinv-22						0.886						1.964						0.373
% SD	50-60 cm				CA/P	>60%					Ca/S	>90%					Ca/Zn	NS

% = % Significant difference, NS = No significant difference, t-test = Student t-test, t-inv-# = Number of samples used in statisical calculations

Appendix 10D Tables 1-12: Ratios of Calcium to other bound minerals including % Significant Difference for each soil depth.

Table 10D-12: Ca:Cd, Ca:Pb Ratios at 50-60 cm depth

	Unlimed			Limed			Unlimed			Limed		
	Ca	Cd	Ca/Cd	Ca	Cd	Ca/Cd	Ca	Pb	Ca/Pb	Ca	Pb	Ca/Pb
Spring 1999	8560	1.35	6341	8670	2.41	3598	8560	15.2	563	8670	33.3	260
	5580	0.96	5813	9150	2.33	3927	5580	5.4	1033	9150	24.6	372
	5040	1.12	4500	4920	0.42	11714	5040	5.6	900	4920	6.8	724
	4860	1.75	2777	6200	0.47	13191	4860	3.6	1350	6200	18.4	337
	3350	0.58	5776	3860	1.13	3416	3350	14.0	239	3860	4.3	898
	2920	0.79	3696	3260	1.25	2608	2920	8.0	365	3260	7.0	466
Fall 1999	2840	1.91					2840	7.2				
	5700	1.08	5278	3660	0.75	4880	5700	8.7	655	3660	12.0	305
	1760	2.13	826	3490	1.70	2053	1760	13.4	131	3490	25.4	137
	6120	0.90	6800	3690	1.91	1932	6120	6.1	1003	3690	15.1	244
	3900	1.94	2010	2340	0.45	5200	3900	15.1	258	2340	18.5	126
Spring 2000	1570	0.93	1688	1290	1.48	872	1570	10.4	151	1290	9.2	140
	1310	1.53	856	1470	1.72	855	1310	14.6	90	1470	7.5	196
	570	1.40	407	4190	0.84	4988	570	18.0	32	4190	6.6	635
	1190	0.91	1308	1900	0.96	1979	1190	2.5	476	1900	7.5	253
	2280	1.05	2171	1660	0.92	1804	2280	7.1	321	1660	6.6	252
	514	1.18	436	1100	2.11	521	514	12.3	42	1100	7.4	149
Fall 2000	1590	1.60	994	2640	2.73	967	1590	11.4	139	2640	7.3	362
	1550	1.72	901	4790	1.60	2994	1550	3.7	419	4790	5.0	958
	3140	0.92	3413	2920	0.84	3476	3140	8.3	378	2920	10.6	275
	2050	1.20	1708	1920	1.21	1587	2050	38.0	54	1920	8.5	226
	2250	1.51	1490	1590	1.25	1272	2250	7.6	296	1590	20.9	76
	2510	0.99	2535	2460	0.90	2733	2510	6.9	364	2460	65.7	37
	5940	1.86	3194	4580	1.41	3248	5940	5.3	1121	4580	5.1	898
Average	3212	1.3	2823	3554	1.34	3470	3212	10.4	451	3554	14.5	362
t-test						0.348						0.300
tinv-22						0.959						1.061
% SD	50-60 cm				Ca/Cd	>80%					Ca/Pb	>70%

% = % Significant difference, NS = No significant difference, t-test = Student t-test, t-inv-# = Number of samples used in statisical calculations

Appendix 10E: Mineral analysis for Cenococcum geophilum (Cg), Quercirhiza fibulocystidiata (Qf), Piceirhiza chordata (Pc) and Lactarius subdulcis (Ls) from unlimed (N) and limed (K) probes.

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Tabelle: Mineralstoffe in Feinwurzelproben (LUFA Speyer)

Probenbezeichnung	LUFA-Journal-Nr.:	Calcium(Ca) mg/kg	Aluminium (Al) mg/kg	Eisen (Fe) mg/kg	Kalium (K) mg/kg
S2 N10 Cg	10079	13900	7660	5230	1130
S2 N10 Cg	10080	3990	9480	7430	1350
F2 N10 Cg	10081	5370	9480	5810	1220
S2 K10 Cg	10082	3330	16360	10100	1870
F2 K10 Cg	10083	7260	13270	8880	2220
S2 N30 Cg	10084	2620	19140	2160	780
S2 K30 Cg	10085	2440	16990	5290	1210
F2 K30 Cg	10086	2970	19190	2420	733
F2 N30 Cg	10087	1810	24910	2030	664
S2 N50 Cg	10088	2760	18160	1930	646
F2 N50 Cg	10089	2210	29290	3210	811
F2 N10 Qf	10090	2120	11650		
S2 K10 Qf	10091	6760	13290		
F2 K10 Qf	10092	5200	15110		
S2 K10 Pc	10093	9560	8160		
F2 K10 Pc	10094	7920	7500		
S2 N10 Pc	10095	2090	1830		
F2 N30 Pc	10096	2320	17770		
S2 K30 Pc	10097	2280	20240		
F2 K30 Pc	10098	2850	20960		
F2 K50 Pc	10099	2050	15410		
S2 N10 Ls	10100	2720	2150		
F2 N10 Ls	10101	7250	5260		
S2 K10 Ls	10102	5970	3740		
F2 K10 Ls	10103	7620	5500		

Appendix 11: Unbound Mineral Analysis

Purpose: To determine content of unbound Aluminum and Calcium and other physiologically important minerals in mycorrhizal roots.

Notes: 1. The dilution factors (Dil.-F.) were 6,00 (400 µl + 2 ml H_2O) 11,00 (200 µl + 2 ml H_2O), and 14 (150 µl + 2 ml H_2O).
2. LOD = Limit of Detection

Appendix 11A: Cytosol mineral analysis. Tables 1-6.

Appendix 11A : Cytosol mineral analysis of fine mycorrhizal oak roots from unlimed (N) and liimed (K) soil at 0-10, 30-40 and 50-60 cm depths.

Table 11A-1: Unbound minerals in unlimed mycorrhizal roots from 0-10 cm depth

Content		Al mg/l	Ca mg/l	Mg mg/l	K mg/l	Na mg/l	Fe mg/l	Mn mg/l	P mg/l	S mg/l	Zn mg/l
LOD		0,1	0,1	0,1	0,2	0,2	0,01	0,01	0,5	1	0,01
Spring 1999	Dil.-F.										
1 N 0-10	6,00	1,8993	36,3160	16,6545	26,8947	28,6465	0,3574	1,2765	11,7730	7,3767	1,8528
2 N 0-10	6,00	11,9655	13,6850	6,9408	18,3118	9,6178	8,6967	4,4522	3,5455	7,6457	1,5741
3 N 0-10	6,00	10,3934	10,8485	6,0089	19,3057	8,0009	6,0800	5,1545	4,3903	6,7059	1,2521
4 N 0-10	6,00	12,6986	8,7444	3,9303	16,4146	8,2029	17,4757	3,5501	4,6915	7,4328	1,3574
5 N 0-10	6,00	9,3647	5,9662	3,9142	33,8754	9,9155	2,5124	1,1947	10,3252	8,7272	0,7992
6 N 0-10	6,00	0,9149	4,7850	4,3740	48,2886	7,7955	0,1773	1,3748	11,7956	9,8183	1,3537
Average		**7,8727**	**13,3909**	**6,9704**	**27,1818**	**12,0298**	**5,8833**	**2,8338**	**7,7535**	**7,9511**	**1,3649**
St.Dev.		**5,1520**	**11,6867**	**4,8996**	**12,2231**	**8,1879**	**6,5847**	**1,7753**	**3,9370**	**1,1253**	**0,3507**
Fall 1999											
7 N 0-10	6,00	7,4424	7,7950	3,7590	20,7813	8,8254	0,8000	1,3968	5,8008	7,4277	0,9682
9 N 0-10	6,00	6,1177	3,7298	2,0327	18,2125	7,7536	1,6769	0,8175	4,7131	6,7004	1,7878
10 N 0-10	6,00	12,1645	15,2281	4,4002	18,3123	11,1873	2,9483	2,6340	7,0140	7,7980	3,2725
11 N 0-10	6,00	11,2965	19,6935	6,7957	25,1508	14,4136	4,7690	3,4686	2,8021	10,4007	1,9236
12 N 0-10	6,00	5,8278	4,4691	2,3647	17,4745	8,5591	1,1308	0,8121	4,0164	9,7663	1,9316
Average		**8,5698**	**10,1831**	**3,8705**	**19,9863**	**10,1478**	**2,2650**	**1,8258**	**4,8693**	**8,4186**	**1,9767**
St.Dev.		**2,9648**	**6,9982**	**1,9036**	**3,1449**	**2,7057**	**1,6214**	**1,1811**	**1,6196**	**1,5862**	**0,8272**
Spring 2000											
100 N 0-10	6,00	8,6172	7,8016	3,9348	29,4002	9,1006	0,2622	3,1704	3,7466	8,0476	0,7250
200 N 0-10	6,00	7,5165	3,0311	1,7183	32,4899	14,5600	0,7813	0,5547	8,6876	6,9416	0,3680
300 N 0-10	6,00	3,3530	7,6540	4,2585	26,2612	12,4376	0,0989	1,4468	12,3689	8,4030	1,2178
400 N 0-10	6,00	9,4558	7,7876	3,3456	20,2004	11,4280	1,3856	2,3684	3,4803	6,6832	2,1295
500 N 0-10	6,00	7,8647	14,8459	5,7057	13,2582	12,1445	5,8144	0,7074	6,6869	7,3060	1,6273
600 N 0-10	6,00	8,6240	36,5569	11,6807	26,9927	29,7631	2,3265	7,4513	2,3702	30,6651	1,8039
Average		7,5719	12,9462	5,1073	24,7671	14,9056	1,7781	2,6165	6,2234	11,3411	1,3119
St.Dev.		**2,1743**	**12,1694**	**3,4713**	**6,9513**	**7,4883**	**2,1381**	**2,5693**	**3,8095**	**9,4892**	**0,6714**
Fall 2000											
700 N 0-10	6,00	1,5813	52,0754	18,2635	13,5874	17,4099	0,4194	3,7174	3,3290	11,2254	0,6974
800 N 0-10	6,00	5,4581	26,3329	11,4072	13,2876	13,2648	1,5157	3,3542	1,7944	8,4060	0,5844
900 N 0-10	6,00	7,5082	17,5618	6,2483	19,4748	13,4980	4,0119	1,8450	3,5386	14,5602	1,2012
1100 N 0-10	6,00	11,2669	21,0132	8,7175	82,0255	22,3825	2,3076	3,3432	8,7846	18,8503	1,4009
1200 N 0-10	6,00	8,0533	13,3779	4,3349	13,8099	11,2712	1,3885	1,0233	1,5572	4,8540	3,9690
1400 N 0-10	6,00	4,0651	17,5686	7,6240	26,1964	20,3411	0,2385	0,8039	10,5692	12,9942	1,0430
1500 N 0-10	6,00	2,4341	27,0972	10,8109	45,4140	27,8574	0,1216	1,0838	5,5717	14,7667	1,4929
1600 N 0-10	6,00	8,7281	31,1674	16,3726	78,5144	32,8919	0,3264	5,8450	12,7651	25,0127	1,3112
Average		6,1369	25,7743	10,4724	36,5387	19,8646	1,2912	2,6270	5,9887	13,8337	1,4625
St.Dev.		**3,3338**	**12,1539**	**4,8286**	**29,0121**	**7,5982**	**1,3449**	**1,7515**	**4,2291**	**6,2007**	**1,0631**

Wurzelextrakte UKS Merzablen, LUFA Speyer, den 02.04.03: LOD=Limit of Detection, Dil.F.=Dilution Factor

Appendix Table 11A-2: Unbound minerals in limed mycorrhizal roots from 0-10 cm depth

Content	Dil.-F.	Al mg/l	Ca mg/l	Mg mg/l	K mg/l	Na mg/l	Fe mg/l	Mn mg/l	P mg/l	S mg/l	Zn mg/l
LOD		0,1	0,1	0,1	0,2	0,2	0,01	0,01	0,5	1	0,01
Spring 1999											
1 K 0-10	6,00	1,1075	81,8953	34,5699	26,0579	34,8538	0,3724	2,5711	12,8579	14,9953	3,2355
2 K 0-10	6,00	6,3163	29,1119	24,0091	15,0639	16,3296	4,8304	5,8655	4,7978	11,6955	2,4334
3 K 0-10	6,00	3,5455	29,5593	28,0943	15,8593	13,1761	1,7051	3,3198	1,9924	9,9756	0,6058
4 K 0-10	6,00	4,4881	19,9920	14,5591	28,7733	18,3031	0,6954	2,6147	3,6598	9,9220	2,4686
5 K 0-10	6,00	2,9648	35,4523	17,0343	9,1799	12,2117	0,1620	1,4207	5,5061	7,7233	2,8833
Average		3,6844	39,2021	23,6534	18,9869	18,9749	1,5531	3,1584	5,7628	10,8623	2,3253
St.Dev.		**1,9203**	**24,4979**	**8,1476**	**8,1719**	**9,2054**	**1,9254**	**1,6594**	**4,1826**	**2,7064**	**1,0160**
Fall 1999											
7 K 0-10	11,00	6,6062	33,8830	24,9510	84,1680	29,1511	2,0196	1,3423	7,1928	12,3550	4,8200
8 K 0-10	6,00	6,9400	19,9424	13,2029	25,7872	12,6520	0,6697	1,9821	3,2381	11,1748	1,1189
9 K 0-10	6,00	8,7194	13,3403	8,8845	26,8550	10,8744	2,0299	1,3279	4,7211	10,6445	1,3186
10 K 0-10	14,33	5,1818	27,4368	12,2252	12,5506	17,4342	0,2043	0,4179	2,9008	5,0004	1,9569
11 K 0-10	6,00	9,3099	21,9918	20,8697	19,8760	9,9318	1,9555	7,6397	3,1307	10,1853	0,8816
12 K 0-10	6,00	6,0134	14,9084	14,2542	44,8465	12,9391	0,4685	2,7161	4,8303	9,0372	0,7119
Average		**7,1284**	**21,9171**	**15,7312**	**35,6805**	**15,4971**	**1,2246**	**2,5710**	**4,3356**	**9,7329**	**1,8013**
St.Dev.		**1,5894**	**7,7490**	**5,9858**	**26,0599**	**7,1717**	**0,8643**	**2,5981**	**1,6292**	**2,5640**	**1,5407**
Spring 2000											
100 K 0-10	6,00	8,2259	27,6014	18,9065	32,8195	17,4627	0,4803	2,5313	4,3924	8,1288	1,3964
200 K 0-10	6,00	4,0672	30,5044	13,4150	23,2130	17,1244	0,5529	3,3674	4,4923	8,7867	1,5765
300 K 0-10	6,00	6,8531	15,1537	11,7174	31,4698	16,3398	0,5690	2,3763	3,9059	15,5416	0,8748
400 K 0-10	6,00	5,9813	39,5301	14,7745	23,9122	26,0404	0,3210	0,9903	5,0386	16,0803	1,3069
500 K 0-10	6,00	3,9531	14,7443	10,9630	9,2768	10,2631	2,6346	2,2626	2,1934	5,4180	0,7987
600 K 0-10	6,00	4,4910	23,9383	14,1786	15,7112	13,1909	1,0670	3,0380	1,8229	13,8939	0,6341
Average		**5,5953**	**25,2454**	**13,9925**	**22,7337**	**16,7369**	**0,9375**	**2,4277**	**3,6409**	**11,3082**	**1,0979**
St.Dev.		**1,7264**	**9,4983**	**2,8100**	**9,0561**	**5,3268**	**0,8683**	**0,8200**	**1,3201**	**4,4394**	**0,3785**
Fall 2000											
800 K 0-10	6,00	3,6446	20,3318	10,3235	14,5830	13,3439	1,0914	1,3173	2,1496	6,6370	1,0002
900 K 0-10	6,00	4,6220	30,4819	13,9640	17,4240	14,1238	0,5720	1,7503	2,2317	7,9135	0,8594
1000 K 0-10	6,00	4,0789	61,1788	20,2962	46,6104	35,4633	0,5481	10,5850	14,3987	27,9955	1,3656
1100 K 0-10	6,00	10,8505	26,5357	15,9129	53,2767	23,5646	0,6581	5,4700	7,0953	19,7726	1,4318
1100 K 0-10	6,00	9,3952	25,2244	11,3516	13,6847	15,0036	2,5019	3,8971	1,6545	9,5598	1,3976
1200 K 0-10	6,00	7,2113	24,1232	10,6144	32,7606	20,0426	0,4814	3,0422	2,4062	14,6600	1,0341
1400 K 0-10	6,00	7,8879	38,0243	20,5700	58,3712	31,2617	1,0540	3,2684	7,3937	22,9994	1,5030
1600 K 0-10	6,00	6,6668	24,8017	9,5395	27,2100	28,6225	0,7705	3,3881	5,1494	8,4326	1,1707
Average		**6,7946**	**31,3377**	**14,0715**	**32,9901**	**22,6782**	**0,9597**	**4,0898**	**5,3099**	**14,7463**	**1,2203**
St.Dev.		**2,5806**	**13,1598**	**4,4451**	**17,8427**	**8,4466**	**0,6633**	**2,9168**	**4,3329**	**8,0012**	**0,2369**

Wurzelextrakte UKS Merzablen, LUFA Speyer, den 02.04.03: LOD=Limit of Detection, Dil.F.=Dilution Factor

Appendix 11A : Cytosol mineral analysis of fine mycorrhizal oak roots from unlimed (N) and liimed (K) soil

Table 11A-3: Unbound minerals in unlimed mycorrhizal roots from 30-40 cm depth

Content LOD		Al mg/l 0,1	Ca mg/l 0,1	Mg mg/l 0,1	K mg/l 0,2	Na mg/l 0,2	Fe mg/l 0,01	Mn mg/l 0,01	P mg/l 0,5	S mg/l 1	Zn mg/l 0,01
Spring 1999	**Dil.-F.**										
1 N 30-40	6,00	13,6758	19,4001	10,6824	47,2135	18,6133	0,0652	1,8851	1,1489	16,0927	0,8919
3 N 30-40	6,00	5,5523	17,2187	7,7652	23,3340	15,0538	0,0236	1,6774	0,4611	4,5509	0,8242
4 N 30-40	6,00	7,2778	4,3652	2,4056	12,4987	8,7754	0,0479	2,7865	0,4594	3,2532	0,4030
5 N 30-40	6,00	6,5020	10,1462	6,8284	11,6148	9,9409	0,0148	2,8701	1,1194	5,2073	0,5462
6 N 30-40	11,00	4,8777	4,9650	3,1163	33,7460	8,4858	0,2027	0,2858	5,5734	5,3648	0,5334
Average		**7,5771**	**11,2190**	**6,1596**	**25,6814**	**12,1738**	**0,0708**	**1,9010**	**1,7524**	**6,8938**	**0,6397**
St.Dev.		**3,5294**	**6,8950**	**3,4218**	**15,0485**	**4,4693**	**0,0764**	**1,0467**	**2,1624**	**5,2092**	**0,2084**
Fall 1999											
7 N 30-40	6,00	8,5751	13,4521	7,5559	40,3995	16,3046	0,0309	1,8615	0,9110	12,1372	0,7487
8 N 30-40	6,00	0,3702	2,2828	0,5708	1,4854	5,2717	0,0482	0,1121	1,0626	1,5171	0,5083
8 N 30-40	14,33	7,2736	39,8689	21,6158	39,9714	48,4603	0,1437	2,4202	0,5355	37,4080	5,6845
9 N 30-40	14,33	19,9214	10,8799	8,3473	55,2593	10,3072	0,1419	4,1241	1,5020	10,0974	2,7409
10 N 30-40	6,00	12,4922	20,7397	5,0177	14,5867	15,6070	0,0957	2,7345	0,3308	5,3171	0,9592
11 N 30-40	6,00	8,9514	13,3652	5,2895	43,4705	11,4666	0,0736	1,8171	0,8770	8,3441	1,0016
12 N 30-40	6,00	10,5440	8,8834	2,2016	17,6349	7,7774	0,0587	2,4484	0,4826	5,3162	1,1186
Average		**9,7326**	**15,6388**	**7,2284**	**30,4011**	**16,4564**	**0,0847**	**2,2168**	**0,8145**	**11,4482**	**1,8231**
St.Dev.		**5,8841**	**12,0397**	**6,9113**	**19,2764**	**14,6522**	**0,0445**	**1,2053**	**0,4019**	**11,9698**	**1,8508**
Spring 2000											
100 N 30-40	6,00	6,9195	2,3659	1,9170	30,1571	11,1492	0,0094	2,0494	0,3094	7,5934	0,4166
200 N 30-40	6,00	2,4448	0,6893	0,5304	32,7416	6,8410	0,2541	0,2283	3,2453	4,6056	0,5210
300 N 30-40	6,00	8,1362	6,5368	3,9604	17,2334	11,2479	0,0309	1,5317	0,4328	5,0392	0,5207
400 N 30-40	6,00	4,6590	5,3823	9,7049	25,5274	13,2411	0,0390	1,4928	0,3502	6,7188	0,4175
500 N 30-40	6,00	3,1848	1,2141	1,6459	49,0071	8,2962	0,0279	0,5355	0,2129	6,7187	0,2481
600 N 30-40	6,00	4,5323	16,2771	7,8507	13,3160	18,8336	0,0467	2,9787	0,4387	16,7121	0,7795
Average		**4,9794**	**5,4109**	**4,2682**	**27,9971**	**11,6015**	**0,0680**	**1,4694**	**0,8315**	**7,8980**	**0,4839**
St.Dev.		**2,1761**	**5,8056**	**3,7111**	**12,6971**	**4,2169**	**0,0920**	**1,0031**	**1,1855**	**4,4626**	**0,1759**
Fall 2000											
700 N 30-40	6,00	0,2640	98,8822	45,0426	62,1843	27,1022	0,0321	13,2958	12,1654	25,9319	1,1445
800 N 30-40	6,00	10,8367	13,1162	7,2531	38,8898	24,6710	0,0136	1,7532	0,4629	18,6933	1,0303
900 N 30-40	6,00	3,7175	2,3117	2,0121	42,4593	9,8111	0,0321	0,7574	0,2267	7,4232	0,5749
1100 N 30-40	6,00	9,6092	21,0475	8,4907	26,4686	19,6216	0,0859	0,9475	0,7887	14,5210	0,7532
1200 N 30-40	6,00	9,1867	3,3968	1,9075	30,5079	11,8027	0,0205	2,4980	1,5158	11,6032	1,0589
1400 N 30-40	6,00	2,6763	11,4510	4,6112	34,8752	19,9476	0,4037	0,2217	0,2661	7,1522	0,4990
1600 N 30-40	6,00	13,8844	26,8190	12,9954	68,4439	23,3422	0,0128	2,8978	1,0084	23,6422	0,8491
Average		**7,1678**	**25,2892**	**11,7589**	**43,4041**	**19,4712**	**0,0858**	**3,1959**	**2,3477**	**15,5667**	**0,8443**
St.Dev.		**4,9724**	**33,6234**	**15,1847**	**15,9521**	**6,4888**	**0,1424**	**4,5555**	**4,3529**	**7,4872**	**0,2487**

Wurzelextrakte UKS Merzablen, LUFA Speyer, den 02.04.03: LOD=Limit of Detection, Dil.F.=Dilution Factor

Appendix 11A : Cytosol mineral analysis of fine mycorrhizal oak roots from unlimed (N) and liimed (K) soil

Table 11A-4: Unbound minerals in limed mycorrhizal roots from 30-40 cm depth

Content		Al mg/l	Ca mg/l	Mg mg/l	K mg/l	Na mg/l	Fe mg/l	Mn mg/l	P mg/l	S mg/l	Zn mg/l
LOD		0,1	0,1	0,1	0,2	0,2	0,01	0,01	0,5	1	0,01
Spring 1999	Dil.-F.										
1 K 30-40	6,00	5,7922	29,9159	25,0850	57,8323	34,8294	0,0600	1,3537	0,6664	27,0423	0,7487
3 K 30-40	11,00	21,2845	39,3029	38,5572	49,7725	40,1780	0,1268	2,6584	0,7127	27,3696	2,0508
Average		**13,5383**	**34,6094**	**31,8211**	**53,8024**	**37,5037**	**0,0934**	**2,0061**	**0,6896**	**27,2059**	**1,3997**
St.Dev.		**10,9547**	**6,6376**	**9,5262**	**5,6992**	**3,7820**	**0,0473**	**0,9226**	**0,0327**	**0,2315**	**0,9208**
Fall 1999											
8 K 30-40	6,00	7,9110	7,1095	7,6569	20,3282	10,1461	0,0439	0,7294	0,5429	6,5355	0,3784
11 K 30-40	11,00	14,0956	14,3178	17,3547	39,4485	11,0282	0,0980	6,1408	0,5350	11,3098	0,8479
12 K 30-40	6,00	9,1001	6,5667	7,4382	21,3794	13,3071	0,0067	1,5972	0,6450	9,6162	0,4462
Average		**10,3689**	**9,3313**	**10,8166**	**27,0520**	**11,4938**	**0,0495**	**2,8225**	**0,5743**	**9,1538**	**0,5575**
St.Dev.		**3,2817**	**4,3269**	**5,6632**	**10,7485**	**1,6311**	**0,0459**	**2,9064**	**0,0614**	**2,4205**	**0,2538**
Spring 2000											
100 K 30-40	6,00	7,0942	3,3691	8,9559	20,3902	12,7679	0,0757	1,1177	5,8096	9,0319	0,4942
200 K 30-40	6,00	9,6193	2,2716	4,5441	26,5638	10,9299	0,0235	0,6668	0,5153	8,8723	0,5306
300 K 30-40	6,00	8,1385	3,1062	8,0536	29,7013	13,9644	0,0182	1,1639	0,9579	11,7413	0,4294
400 K 30-40	6,00	8,6124	10,1737	13,4863	15,7333	10,2348	0,0727	4,1265	1,0826	6,7018	0,4591
500 K 30-40	6,00	2,0138	1,3371	4,6841	40,4834	9,1957	0,0101	0,6650	0,2200	6,3754	0,1105
600 K 30-40	6,00	5,4744	13,5646	9,9906	12,6969	19,4210	0,0991	0,9721	0,3917	17,1074	0,4284
Average		**6,8254**	**5,6370**	**8,2857**	**24,2615**	**12,7523**	**0,0499**	**1,4520**	**1,4962**	**9,9717**	**0,4087**
St.Dev.		**2,7486**	**4,9958**	**3,3890**	**10,1931**	**3,6946**	**0,0371**	**1,3277**	**2,1390**	**3,9942**	**0,1513**
Fall 2000											
800 K 30-40	6,00	7,1289	7,3539	9,8566	33,3625	18,1311	0,0136	0,8129	0,3490	16,2572	0,5258
900 K 30-40	6,00	4,0316	1,6868	2,9938	27,0690	10,2686	0,0216	0,3938	0,4198	9,6694	0,1815
1000 K 30-40	6,00	2,2962	4,0127	4,1985	21,7890	10,9773	0,0170	0,5498	0,4972	4,8347	0,1839
1100 K 30-40	6,00	14,6538	15,1334	12,6126	42,0108	21,7922	0,0351	1,7277	0,7616	18,4374	0,5656
1100 K 30-40	6,00	16,7070	14,7684	13,7290	25,2430	16,1335	0,0496	2,7085	0,8952	10,1602	0,5443
1200 K 30-40	6,00	2,3704	8,6608	6,8427	14,4876	9,9696	0,0212	3,1746	0,5975	6,6495	0,1945
1400 K 30-40	11,00	7,0650	8,5989	6,1687	25,6115	17,8030	0,0368	1,1401	0,7918	10,7142	0,2655
Average		**7,7504**	**8,6021**	**8,0574**	**27,0819**	**15,0108**	**0,0279**	**1,5010**	**0,6160**	**10,9604**	**0,3516**
St.Dev.		**5,7916**	**5,0188**	**4,1176**	**8,7034**	**4,6359**	**0,0130**	**1,0836**	**0,2059**	**4,8723**	**0,1837**

Wurzelextrakte UKS Merzablen, LUFA Speyer, den 02.04.03: LOD=Limit of Detection, Dil.F.=Dilution Factor

Appendix 11A : Cytosol mineral analysis of fine mycorrhizal oak roots from unlimed (N) and liimed (K) soil

Table 11A-5: Unbound minerals in unlimed mycorrhizal roots from 50-60 cm depth

Content		Al mg/l	Ca mg/l	Mg mg/l	K mg/l	Na mg/l	Fe mg/l	Mn mg/l	P mg/l	S mg/l	Zn mg/l
LOD		0,1	0,1	0,1	0,2	0,2	0,01	0,01	0,5	1	0,01
Spring 1999	Dil.-F.										
1 N 50-60	6,00	8,2940	29,6133	12,5576	33,9358	20,7129	0,0496	1,9381	0,5257	12,0602	1,4119
4 N 50-60	6,00	3,8473	9,1650	3,7692	11,0684	9,5892	0,0155	1,4266	0,8063	5,8973	2,0925
5 N 50-60	6,00	3,8785	7,5328	1,6740	8,5267	9,2701	0,0798	0,5506	0,4323	2,9443	0,7511
6 N 50-60	6,00	15,8529	8,8314	5,4216	63,4993	18,4929	0,0551	0,5460	0,2435	18,1477	1,5296
Average		**7,9682**	**13,7856**	**5,8556**	**29,2575**	**14,5163**	**0,0500**	**1,1153**	**0,5020**	**9,7624**	**1,4462**
St.Dev.		**5,6563**	**10,5753**	**4,7239**	**25,5278**	**5,9445**	**0,0265**	**0,6872**	**0,2344**	**6,7581**	**0,5505**
Fall 1999											
7 N 50-60	6,00	9,6459	6,8010	4,2117	30,7042	10,4759	0,1528	1,0660	0,6945	8,6725	1,1483
8 N 50-60	11,00	4,5951	14,6548	7,4020	17,7796	19,7530	0,0808	1,2122	0,7657	12,7587	1,1250
9 N 50-60	21,00	9,3858	15,4369	7,5142	10,9206	12,2644	0,0719	1,0218	0,3885	6,5577	6,8160
9 N 50-60	21,00	15,5337	17,0055	11,7954	23,7588	13,0227	0,3947	3,8995	0,8798	10,4925	1,6349
10 N 50-60	6,00	5,5945	16,1294	9,7559	15,7981	15,2424	0,0005	1,7178	0,5609	7,3877	1,3538
12 N 50-60	6,00	7,2418	10,2950	3,8916	33,5874	11,7645	0,0449	1,4946	0,6970	6,6917	1,5746
Average		**8,6661**	**13,3871**	**7,4285**	**22,0915**	**13,7538**	**0,1243**	**1,7353**	**0,6644**	**8,7601**	**2,2754**
St.Dev.		**3,9161**	**3,9840**	**3,0774**	**8,8555**	**3,3365**	**0,1416**	**1,0930**	**0,1706**	**2,4499**	**2,2343**
Spring 2000											
100 N 50-60	6,00	8,4507	11,9616	5,6682	59,3850	16,0347	0,0637	2,7359	0,6263	13,3422	1,2493
200 N 50-60	6,00	9,6680	6,6684	2,9827	27,0815	11,6776	0,0637	0,8777	0,6714	8,2976	3,5613
400 N 50-60	6,00	9,0458	4,9477	4,9261	37,8474	11,3864	0,0052	3,9438	0,3525	9,3229	1,0373
500 N 50-60	6,00	3,7668	4,0529	3,0323	34,1414	9,7690	0,0127	1,0488	0,6000	6,3720	0,8081
600 N 50-60	6,00	5,5278	2,0901	1,7224	17,4074	7,3734	0,0292	1,1123	0,4754	6,0491	1,0698
Average		**7,2918**	**5,9441**	**3,6663**	**35,1725**	**11,2482**	**0,0349**	**1,9437**	**0,5451**	**8,6768**	**1,5452**
St.Dev.		**2,5300**	**3,7469**	**1,6002**	**15,6167**	**3,1747**	**0,0277**	**1,3469**	**0,1299**	**2,9387**	**1,1379**
Fall 2000											
700 N 50-60	6,00	10,1742	6,7904	3,4474	51,1702	16,8266	0,3848	1,1649	5,9280	20,1284	0,9090
800 N 50-60	6,00	5,3143	9,2772	6,8537	34,3415	25,0806	0,0107	1,0237	0,3858	16,9167	1,4295
900 N 50-60	6,00	3,2942	3,4239	2,1798	36,9821	15,6118	0,0127	0,4154	0,3758	6,9058	0,8152
1000 N 50-60	11,00	0,8658	3,5984	2,2149	27,1662	9,5690	-0,0106	0,8943	0,1837	1,9629	1,0751
1100 N 50-60	6,00	14,6273	6,7143	2,7410	46,0364	13,0249	0,0708	1,2390	2,3604	12,9017	0,6534
1200 N 50-60	6,00	2,6490	3,5187	1,7961	41,4655	10,6244	0,0147	1,0952	0,7615	7,6552	0,6809
1600 N 50-60	6,00	15,1913	10,1338	6,4696	61,4082	12,8025	0,0928	1,8149	0,9106	14,8286	0,9080
Average		**7,4452**	**6,2081**	**3,6718**	**42,6528**	**14,7914**	**0,0823**	**1,0925**	**1,5580**	**11,6142**	**0,9245**
St.Dev.		**5,8750**	**2,8054**	**2,1109**	**11,3889**	**5,2025**	**0,1384**	**0,4185**	**2,0597**	**6,3717**	**0,2655**

Wurzelextrakte UKS Merzablen, LUFA Speyer, den 02.04.03: LOD=Limit of Detection, Dil.F.=Dilution Factor

Appendix 11A : Cytosol mineral analysis of fine mycorrhizal oak roots from unlimed (N) and liimed (K) soil

Table 11A-6: Unbound minerals in unlimed mycorrhizal roots from 50-60 cm depth

Content		Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
		mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
LOD		0,1	0,1	0,1	0,2	0,2	0,01	0,01	0,5	1	0,01
Spring 1999	Dil.-F.										
1 K 50-60	6,00	4,9057	14,1544	11,6868	34,5567	14,7021	0,0280	0,7399	0,6719	6,9594	0,6049
2 K 50-60	6,00	5,9110	32,4870	11,4575	14,3878	14,0497	0,1685	1,3696	1,2839	8,8876	0,5502
3 K 50-60	6,00	8,0921	19,3213	10,3469	11,8211	11,2999	0,0810	1,4779	0,7116	7,5482	0,4291
4 K 50-60	14,33	4,7564	17,3964	7,3127	12,9001	10,8084	0,0931	1,8034	1,0497	7,1615	1,5284
4 K 50-60	14,33	5,3297	27,5013	13,2108	20,9035	12,9587	0,0734	2,7729	0,8406	9,4634	1,4059
5 K 50-60	6,00	3,0967	26,9992	7,5185	9,0017	14,9354	0,0256	0,9370	0,6153	10,3854	0,2585
6 K 50-60	14,33	6,3767	7,0116	7,4854	34,8614	9,0418	0,1044	1,0614	0,7306	9,0798	0,9459
Average		**5,4955**	**20,6959**	**9,8598**	**19,7760**	**12,5423**	**0,0820**	**1,4517**	**0,8434**	**8,4979**	**0,8176**
St.Dev.		**1,5474**	**8,8309**	**2,4140**	**10,8243**	**2,2226**	**0,0488**	**0,6832**	**0,2409**	**1,2936**	**0,4912**
Fall 1999											
9 K 50-60	14,33	12,8854	16,2872	10,9925	15,9386	10,5566	0,0884	1,5928	0,8376	7,5451	1,5375
10 K 50-60	14,33	1,0467	41,8664	8,8505	6,2232	10,6538	0,0388	1,2160	0,7326	3,1971	1,3567
11 K 50-60	14,33	3,7558	3,0047	2,5477	7,3098	7,0415	0,1203	0,5231	2,0212	4,4759	1,1201
12 K 50-60	6,00	5,9711	5,8532	7,1153	14,5548	9,8884	0,0672	1,5465	0,6986	4,4433	0,3210
Average		**5,9147**	**16,7529**	**7,3765**	**11,0066**	**9,5351**	**0,0787**	**1,2196**	**1,0725**	**4,9153**	**1,0838**
St.Dev.		**5,0646**	**17,6892**	**3,5886**	**4,9484**	**1,6969**	**0,0344**	**0,4937**	**0,6352**	**1,8515**	**0,5365**
Spring 2000											
100 K 50-60	6,00	6,3208	3,2606	4,7631	19,0689	9,4872	0,0154	0,6823	0,5609	7,4411	0,4469
200 K 50-60	6,00	8,4250	1,2837	3,4071	32,5678	8,2676	0,0072	0,5665	0,4143	8,7795	0,4745
300 K 50-60	6,00	0,9284	2,1244	2,6167	14,4305	8,5917	0,0429	0,3495	0,2669	1,6062	0,5404
400 K 50-60	6,00	6,4399	4,5913	6,4675	32,0949	9,3181	0,0056	1,8908	0,4826	8,8866	0,7664
500 K 50-60	6,00	1,1201	0,9298	1,7406	39,3311	7,4390	0,0048	0,4072	0,2762	2,6770	0,2478
600 K 50-60	6,00	5,4868	13,0189	7,0316	12,7995	11,7813	0,0378	1,2669	0,7457	6,6397	0,4282
Average		**4,7869**	**4,2014**	**4,3378**	**25,0488**	**9,1475**	**0,0190**	**0,8605**	**0,4578**	**6,0050**	**0,4840**
St.Dev.		**3,0706**	**4,5236**	**2,1235**	**11,0338**	**1,4889**	**0,0171**	**0,6019**	**0,1819**	**3,1271**	**0,1693**
Fall 2000											
800 K 50-60	6,00	2,5729	3,0899	5,2847	30,0417	9,0102	0,0033	0,4003	0,5617	6,0492	0,3192
900 K 50-60	6,00	3,9777	4,1832	6,6369	44,6512	13,0537	-0,0003	0,4931	0,3795	12,4197	0,5362
1000 K 50-60	6,00	8,9363	3,8628	10,4232	33,5216	14,0349	0,0139	0,6013	0,6053	13,9722	0,3649
1100 K 50-60	6,00	15,0106	9,4552	10,9762	39,1008	17,4438	0,0590	2,6727	1,0598	13,7130	0,7299
1100 K 50-60	6,00	11,6446	7,8492	10,2619	48,2568	17,4230	0,0260	2,8418	1,4765	16,6608	0,4731
1200 K 50-60	6,00	6,9067	5,0120	5,0127	29,0159	12,6351	0,0182	2,4107	0,6611	12,1631	0,6250
1400 K+A24 50-6	6,00	6,4453	8,2844	5,1694	31,0704	9,6073	0,0107	0,7965	0,4910	8,9936	0,3321
Average		**7,9277**	**5,9624**	**7,6807**	**36,5226**	**13,3154**	**0,0187**	**1,4595**	**0,7478**	**11,9959**	**0,4829**
St.Dev.		**4,3305**	**2,5126**	**2,7477**	**7,6103**	**3,3479**	**0,0198**	**1,1195**	**0,3857**	**3,4928**	**0,1568**

Wurzelextrakte UKS Merzablen, LUFA Speyer, den 02.04.03: LOD=Limit of Detection, Dil.F.=Dilution Factor

Appendix 11B Root Extracts Analyzed by UKS Merzalben, LUFA Speyer, 03.04.03

	Al N	Al K	Ca N	Ca K	Mg N	Mg K	K N	K K	Na N	Na K	Fe N	Fe K	Mn N	Mn K	P N	P K	S N	S K	Zn N	Zn K
Spring 1999																				
	1,899		36,316		16,654		26,895		28,646		0,357		1,276		11,773		7,377		1,853	
	11,965	1,107	13,685	81,895	6,941	34,570	18,312	26,058	9,618	34,854	8,697	0,372	4,452	2,571	3,546	12,858	7,646	14,995	1,574	3,236
	10,393	6,316	10,848	29,112	6,009	24,009	19,306	15,064	8,001	16,330	6,080	4,830	5,154	5,865	4,390	4,798	6,706	11,695	1,252	2,433
	12,699	3,546	8,744	29,559	3,930	28,094	16,415	15,859	8,203	13,176	17,476	1,705	3,550	3,320	4,692	1,992	7,433	9,976	1,357	0,606
	9,365	4,488	5,966	19,992	3,914	14,559	33,875	28,773	9,915	18,303	2,512	0,695	1,195	2,615	10,325	3,660	8,727	9,922	0,799	2,469
	0,915	2,965	4,785	35,452	4,374	17,034	48,289	9,180	7,795	12,212	0,177	0,162	1,375	1,421	11,796	5,506	9,818	7,723	1,354	2,883
Ave.	***7,873***	***3,684***	***13,391***	***39,202***	***6,970***	***23,653***	***27,182***	***18,987***	***12,030***	***18,975***	***5,883***	***1,553***	***2,834***	***3,158***	***7,754***	***5,763***	***7,951***	***10,862***	***1,365***	***2,325***
SD	***5,152***	***1,920***	***11,687***	***24,498***	***4,900***	***8,148***	***12,223***	***8,172***	***8,188***	***9,205***	***6,585***	***1,925***	***1,775***	***1,659***	***3,937***	***4,183***	***1,125***	***2,706***	***0,351***	***1,016***
tt		***0,075***		***0,037***		***0,005***		***0,363***		***0,055***		***0,140***		***0,982***		***0,706***		***0,158***		***0,083***
tinv		***2,391***		***3,089***		***5,727***		***1,026***		***2,680***		***1,837***		***0,024***		***0,406***		***1,733***		***2,295***
%		***>90%***	***S***	***>95%***	***HS***	***>99%***		***>60%***		***>90%***		***>80%***		***NS***		***NS***		***>80%***		***>90%***
Fall 1999																				
		6,606		33,883		24,951		84,168		29,151		2,020		1,342		7,193		12,355		4,820
	7,442	6,940	7,795	19,942	3,759	13,203	20,781	25,787	8,825	12,652	0,800	0,670	1,397	1,982	5,801	3,238	7,428	11,175	0,968	1,119
	6,118	8,719	3,730	13,340	2,033	8,884	18,212	26,855	7,754	10,874	1,677	2,030	0,817	1,328	4,713	4,721	6,700	10,645	1,788	1,319
	12,165	5,182	15,228	27,437	4,400	12,225	18,312	12,551	11,187	17,434	2,948	0,204	2,634	0,418	7,014	2,901	7,798	5,000	3,273	1,957
	11,296	9,310	19,693	21,992	6,796	20,870	25,151	19,876	14,414	9,932	4,769	1,955	3,469	7,640	2,802	3,131	10,401	10,185	1,924	0,882
	5,828	6,013	4,469	14,908	2,365	14,254	17,475	44,846	8,559	12,939	1,131	0,468	0,812	2,716	4,016	4,830	9,766	9,037	1,932	0,712
Ave.	***8,570***	***7,128***	***10,183***	***21,917***	***3,870***	***15,731***	***19,986***	***35,681***	***10,148***	***15,497***	***2,265***	***1,225***	***1,826***	***2,571***	***4,869***	***4,336***	***8,419***	***9,733***	***1,977***	***1,801***
SD	***2,965***	***1,589***	***6,998***	***7,749***	***1,904***	***5,986***	***3,145***	***26,060***	***2,706***	***7,172***	***1,621***	***0,864***	***1,181***	***2,598***	***1,620***	***1,629***	***1,586***	***2,564***	***0,827***	***1,541***
tt		***0,449***		***0,007***		***0,002***		***0,377***		***0,230***		***0,145***		***0,395***		***0,311***		***0,582***		***0,047***
tinv		***0,839***		***5,104***		***7,559***		***0,992***		***1,416***		***1,805***		***0,953***		***1,160***		***0,598***		***2,834***
%		***>50%***	***HS***	***>99%***	***HS***	***>99%***		***>60%***		***>70%***		***>80%***		***>60%***		***>60%***		***NS***	***S***	***>95%***

Table [| -1 : Unbound minerals /mg/l) found in unlimed (N) and limed (K) roots at 0-10 cm depth in 1999.

Statistical Analysis Including: Ave. = Average, SD = Standard Deviation, tt = Student t-test, tinv = Inverse of t-test, % = Significant Difference, S = Significant, HS = Highly Significant, NS = Not Signficant.

	Al N	Al K	Ca N	Ca K	Mg N	Mg K	K N	K K	Na N	Na K	Fe N	Fe K	Mn N	Mn K	P N	P K	S N	S K	Zn N	Zn K
Spring 2000																				
	8,617	8,226	7,802	27,601	3,935	18,907	29,400	32,819	9,101	17,463	0,262	0,480	3,170	2,531	3,747	4,392	8,048	8,129	0,725	1,396
	7,516	4,067	3,031	30,504	1,718	13,415	32,490	23,213	14,560	17,124	0,781	0,553	0,555	3,367	8,688	4,492	6,942	8,787	0,368	1,577
	3,353	6,853	7,654	15,154	4,259	11,717	26,261	31,470	12,438	16,340	0,099	0,569	1,447	2,376	12,369	3,906	8,403	15,542	1,218	0,875
	9,456	5,981	7,788	39,530	3,346	14,775	20,200	23,912	11,428	26,040	1,386	0,321	2,368	0,990	3,480	5,039	6,683	16,080	2,129	1,307
	7,865	3,953	14,846	14,744	5,706	10,963	13,258	9,277	12,144	10,263	5,814	2,635	0,707	2,263	6,687	2,193	7,306	5,418	1,627	0,799
	8,624	4,491	36,557	23,938	11,681	14,179	26,993	15,711	29,763	13,191	2,326	1,067	7,451	3,038	2,370	1,823	30,665	13,894	1,804	0,634
Ave.	*7,572*	*5,595*	*12,946*	*25,245*	*5,107*	*13,993*	*24,767*	*22,734*	*14,906*	*16,737*	*1,778*	*0,937*	*2,616*	*2,428*	*6,223*	*3,641*	*11,341*	*11,308*	*1,312*	*1,098*
SD	*2,174*	*1,726*	*12,169*	*9,498*	*3,471*	*2,810*	*6,951*	*9,056*	*7,488*	*5,327*	*2,138*	*0,868*	*2,569*	*0,820*	*3,809*	*1,320*	*9,489*	*4,439*	*0,671*	*0,378*
tt		*0,169*		*0,138*		*0,005*		*0,518*		*0,690*		*0,184*		*0,864*		*0,158*		*0,993*		*0,604*
tinv		*1,608*		*1,762*		*4,696*		*0,695*		*0,423*		*1,543*		*0,181*		*1,661*		*0,009*		*0,554*
%		*>80%*		*>80%*		*>99%*		*NS*		*NS*		*>80%*		*NS*		*>80%*		*NS*		*NS*
Fall 2000																				
	1,581	3,645	52,075	20,332	18,264	10,324	13,587	14,583	17,410	13,344	0,419	1,091	3,717	1,317	3,329	2,150	11,225	6,637	0,697	1,000
	5,458	4,622	26,333	30,482	11,407	13,964	13,288	17,424	13,265	14,124	1,516	0,572	3,354	1,750	1,794	2,232	8,406	7,913	0,584	0,859
	7,508	4,079	17,562	61,179	6,248	20,296	19,475	46,610	13,498	35,463	4,012	0,548	1,845	10,585	3,539	14,399	14,560	27,995	1,201	1,366
	11,267	10,850	21,013	26,536	8,717	15,913	82,026	53,277	22,383	23,565	2,308	0,658	3,343	5,470	8,785	7,095	18,850	19,773	1,401	1,432
	8,053	9,395	13,378	25,224	4,335	11,352	13,810	13,685	11,271	15,004	1,389	2,502	1,023	3,897	1,557	1,654	4,854	9,560	3,969	1,398
	4,065	7,211	17,569	24,123	7,624	10,614	26,196	32,761	20,341	20,043	0,238	0,481	0,804	3,042	10,569	2,406	12,994	14,660	1,043	1,034
	2,434	7,888	27,097	38,024	10,811	20,570	45,414	58,371	27,857	31,262	0,122	1,054	1,084	3,268	5,572	7,394	14,767	22,999	1,493	1,503
	8,728	6,667	31,167	24,802	16,373	9,540	78,514	27,210	32,892	28,622	0,326	0,771	5,845	3,388	12,765	5,149	25,013	8,433	1,311	1,171
Ave.	*6,137*	*6,795*	*25,774*	*31,338*	*10,472*	*14,072*	*36,539*	*32,990*	*19,865*	*22,678*	*1,291*	*0,960*	*2,627*	*4,090*	*5,989*	*5,310*	*13,834*	*14,746*	*1,463*	*1,220*
SD	*3,334*	*2,581*	*12,154*	*13,160*	*4,829*	*4,445*	*29,012*	*17,843*	*7,598*	*8,447*	*1,345*	*0,663*	*1,752*	*2,917*	*4,229*	*4,333*	*6,201*	*8,001*	*1,063*	*0,237*
tt		*0,542*		*0,476*		*0,228*		*0,698*		*0,369*		*0,572*		*0,301*		*0,756*		*0,782*		*0,496*
tinv		*0,640*		*0,753*		*1,322*		*0,404*		*0,959*		*0,592*		*1,116*		*0,323*		*0,288*		*0,719*
%		*NS*		*>50%*		*>70%*		*NS*		*>60%*		*NS*		*>60%*		*NS*		*NS*		*NS*

Table 11 -2 : Unbound minerals (mg/l) found in unlimed (N) and limed (K) roots at 0-10 cm depth in 2000.

Statistical Analysis Including: Ave. = Average, SD = Standard Deviation, tt = Student t-test, tinv = Inverse of t-test, % = Significant Difference, S = Significant, HS = Highly Significant, NS = Not Signficant.

Appendix 11B Root Extracts Analyzed by UKS Merzalben, LUFA Speyer, 03.04.03

	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
Spring 1999																				
	13,676		19,400		10,682		47,214		18,613		0,065		1,885		1,149		16,093		0,892	
	5,552		17,219		7,765		23,334		15,054		0,024		1,677		0,461		4,551		0,824	
	7,278		4,365		2,406		12,499		8,775		0,048		2,786		0,459		3,253		0,403	
	6,502	5,792	10,146	29,916	6,828	25,085	11,615	57,832	9,941	34,829	0,015	0,060	2,870	1,354	1,119	0,666	5,207	27,042	0,546	0,749
	4,878	21,284	4,965	39,303	3,116	38,557	33,746	49,772	8,486	40,178	0,203	0,127	0,286	2,658	5,573	0,713	5,365	27,370	0,533	2,051
Ave.	*7,577*	*13,538*	*11,219*	*34,609*	*6,160*	*31,821*	*25,681*	*53,802*	*12,174*	*37,504*	*0,071*	*0,093*	*1,901*	*2,006*	*1,752*	*0,690*	*6,894*	*27,206*	*0,640*	*1,400*
SD	*3,529*	*10,955*	*6,895*	*6,638*	*3,422*	*9,526*	*15,049*	*5,699*	*4,469*	*3,782*	*0,076*	*0,047*	*1,047*	*0,923*	*2,162*	*0,033*	*5,209*	*0,231*	*0,208*	*0,921*
tt		*0,528*		*0,167*		*0,197*		*0,288*		*0,076*		*0,842*		*0,862*		*0,441*		*0,002*		*0,416*
tinv		*0,917*		*3,714*		*3,125*		*2,062*		*8,316*		*0,253*		*0,220*		*1,206*		*258,1*		*1,308*
%		*NS*		*>80%*		*>80%*		*>70%*		*>90%*		*NS*		*NS*		*>50%*	*HS*	*>99%*		*>50%*
Fall 1999																				
	8,575		13,452		7,556		40,400		16,305		0,031		1,861		0,911		12,137		0,749	
	0,370		2,283		0,571		1,485		5,272		0,048		0,112		1,063		1,517		0,508	
	7,274		39,869		21,616		39,971		48,460		0,144		2,420		0,536		37,408		5,685	
	19,921		10,880		8,347		55,259		10,307		0,142		4,124		1,502		10,097		2,741	
	12,492	7,911	20,740	7,110	5,018	7,657	14,587	20,328	15,607	10,146	0,096	0,044	2,735	0,729	0,331	0,543	5,317	6,536	0,959	0,378
	8,951	14,096	13,365	14,318	5,290	17,355	43,470	39,448	11,467	11,028	0,074	0,098	1,817	6,141	0,877	0,535	8,344	11,310	1,002	0,848
	10,544	9,100	8,883	6,567	2,202	7,438	17,635	21,379	7,777	13,307	0,059	0,007	2,448	1,597	0,483	0,645	5,316	9,616	1,119	0,446
Ave.	*9,733*	*10,369*	*15,639*	*9,331*	*7,228*	*10,817*	*30,401*	*27,052*	*16,456*	*11,494*	*0,085*	*0,050*	*2,217*	*2,822*	*0,815*	*0,574*	*11,448*	*9,154*	*1,823*	*0,557*
SD	*5,884*	*3,282*	*12,040*	*4,327*	*6,911*	*5,663*	*19,276*	*10,749*	*14,652*	*1,631*	*0,045*	*0,046*	*1,205*	*2,906*	*0,402*	*0,061*	*11,970*	*2,420*	*1,851*	*0,254*
tt		*0,928*		*0,375*		*0,142*		*0,603*		*0,973*		*0,407*		*0,825*		*0,957*		*0,087*		*0,099*
tinv		*0,102*		*1,131*		*2,365*		*0,612*		*0,039*		*1,040*		*0,251*		*0,061*		*3,170*		*2,934*
%		*NS*		*>60%*		*>80%*		*NS*		*NS*		*>50%*		*NS*		*NS*		*>90%*		*>90%*

Table II-3 : Unbound minerals (mg/l) found in unlimed (N) and limed (K) roots at 30-40 cm depth in 1999.

Statistical Analysis Including: Ave. = Average, SD = Standard Deviation, tt = Student t-test, tinv = Inverse of t-test, % = Significant Difference, S = Significant, HS = Highly Significant, NS = Not Signficant.

Appendix 11B Root Extracts Analyzed by UKS Merzalben, LUFA Speyer, 03.04.03

	Al N	Al K	Ca N	Ca K	Mg N	Mg K	K N	K K	Na N	Na K	Fe N	Fe K	Mn N	Mn K	P N	P K	S N	S K	Zn N	Zn K
Spring 2000																				
	6,919	7,094	2,366	3,369	1,917	8,956	30,157	20,390	11,149	12,768	0,009	0,076	2,049	1,118	0,309	5,810	7,593	9,032	0,417	0,494
	2,445	9,619	0,689	2,272	0,530	4,544	32,742	26,564	6,841	10,930	0,254	0,024	0,228	0,667	3,245	0,515	4,606	8,872	0,521	0,531
	8,136	8,138	6,537	3,106	3,960	8,054	17,233	29,701	11,248	13,964	0,031	0,018	1,532	1,164	0,433	0,958	5,039	11,741	0,521	0,429
	4,659	8,612	5,382	10,174	9,705	13,486	25,527	15,733	13,241	10,235	0,039	0,073	1,493	4,126	0,350	1,083	6,719	6,702	0,418	0,459
	3,185	2,014	1,214	1,337	1,646	4,684	49,007	40,483	8,296	9,196	0,028	0,010	0,535	0,665	0,213	0,220	6,719	6,375	0,248	0,111
	4,532	5,474	16,277	13,565	7,851	9,991	13,316	12,697	18,834	19,421	0,047	0,099	2,979	0,972	0,439	0,392	16,712	17,107	0,780	0,428
Ave.	***4,979***	***6,825***	***5,411***	***5,637***	***4,268***	***8,286***	***27,997***	***24,261***	***11,602***	***12,752***	***0,068***	***0,050***	***1,469***	***1,452***	***0,832***	***1,496***	***7,898***	***9,972***	***0,484***	***0,409***
SD	***2,176***	***2,749***	***5,806***	***4,996***	***3,711***	***3,389***	***12,697***	***10,193***	***4,217***	***3,695***	***0,092***	***0,037***	***1,003***	***1,328***	***1,185***	***2,139***	***4,463***	***3,994***	***0,176***	***0,151***
tt		***0,208***		***0,861***		***0,002***		***0,339***		***0,294***		***0,702***		***0,979***		***0,570***		***0,131***		***0,296***
tinv		***1,445***		***0,184***		***5,951***		***1,058***		***1,171***		***0,405***		***0,027***		***0,608***		***1,803***		***1,168***
%		***>70%***		***NS***	***HS***	***>99%***		***>60%***		***>70%***		***NS***		***NS***		***NS***		***>80%***		***>70%***
Fall 2000																				
	0,264	7,129	98,882	7,354	45,043	9,857	62,184	33,363	27,102	18,131	0,032	0,014	13,296	0,813	12,165	0,349	25,932	16,257	1,145	0,526
	10,837	4,032	13,116	1,687	7,253	2,994	38,890	27,069	24,671	10,269	0,014	0,022	1,753	0,394	0,463	0,420	18,693	9,669	1,030	0,181
	3,717	2,296	2,312	4,013	2,012	4,199	42,459	21,789	9,811	10,977	0,032	0,017	0,757	0,550	0,227	0,497	7,423	4,835	0,575	0,184
	9,609	14,654	21,047	15,133	8,491	12,613	26,469	42,011	19,622	21,792	0,086	0,035	0,947	1,728	0,789	0,762	14,521	18,437	0,753	0,566
	9,187	16,707	3,397	14,768	1,907	13,729	30,508	25,243	11,803	16,134	0,021	0,050	2,498	2,708	1,516	0,895	11,603	10,160	1,059	0,544
	2,676	2,370	11,451	8,661	4,611	6,843	34,875	14,488	19,948	9,970	0,404	0,021	0,222	3,175	0,266	0,598	7,152	6,650	0,499	0,194
	13,884	7,065	26,819	8,599	12,995	6,169	68,444	25,611	23,342	17,803	0,013	0,037	2,898	1,140	1,008	0,792	23,642	10,714	0,849	0,265
Ave.	***7,168***	***7,750***	***25,289***	***8,602***	***11,759***	***8,057***	***43,404***	***27,082***	***19,471***	***15,011***	***0,086***	***0,028***	***3,196***	***1,501***	***2,348***	***0,616***	***15,567***	***10,960***	***0,844***	***0,352***
SD	***4,972***	***5,792***	***33,623***	***5,019***	***15,185***	***4,118***	***15,952***	***8,703***	***6,489***	***4,636***	***0,142***	***0,013***	***4,555***	***1,084***	***4,353***	***0,206***	***7,487***	***4,872***	***0,249***	***0,184***
tt		***0,808***		***0,246***		***0,541***		***0,058***		***0,148***		***0,333***		***0,404***		***0,344***		***0,090***		***0,001***
tinv		***0,254***		***1,287***		***0,647***		***2,335***		***1,659***		***1,053***		***0,897***		***1,028***		***2,022***		***5,927***
%		***NS***		***>70%***		***NS***		***>90%***		***>80%***		***>60%***		***>50%***		***>60%***		***>90%***	***HS***	***>99%***

Table II-4 : Unbound minerals (mg/l) found in unlimed (N) and limed (K) roots at 30-40 cm depth in 2000.

Statistical Analysis Including: Ave. = Average, SD = Standard Deviation, tt = Student t-test, tinv = Inverse of t-test, % = Significant Difference, S = Significant, HS = Highly Significant, NS = Not Signficant.

Appendix 11B

Root Extracts Analyzed by UKS Merzalben, LUFA Speyer, 03.04.03

	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
Spring 1999																				
		4,906		14,154		11,687		34,557		14,702		0,028		0,740		0,672		6,959		0,605
		5,911		32,487		11,458		14,388		14,050		0,169		1,370		1,284		8,888		0,550
		8,092		19,321		10,347		11,821		11,300		0,081		1,478		0,712		7,548		0,429
	8,294	4,756	29,613	17,396	12,558	7,313	33,936	12,900	20,713	10,808	0,050	0,093	1,938	1,803	0,526	1,050	12,060	7,161	1,412	1,528
	3,847	5,330	9,165	27,501	3,769	13,211	11,068	20,903	9,589	12,959	0,015	0,073	1,427	2,773	0,806	0,841	5,897	9,463	2,093	1,406
	3,878	3,097	7,533	26,999	1,674	7,519	8,527	9,002	9,270	14,935	0,080	0,026	0,551	0,937	0,432	0,615	2,944	10,385	0,751	0,259
	15,853	6,377	8,831	7,012	5,422	7,485	63,499	34,861	18,493	9,042	0,055	0,104	0,546	1,061	0,243	0,731	18,148	9,080	1,530	0,946
Ave.	***7,968***	***5,495***	***13,786***	***20,696***	***5,856***	***9,860***	***29,258***	***19,776***	***14,516***	***12,542***	***0,050***	***0,082***	***1,115***	***1,452***	***0,502***	***0,843***	***9,762***	***8,498***	***1,446***	***0,818***
SD	***5,656***	***1,547***	***10,575***	***8,831***	***4,724***	***2,414***	***25,528***	***10,824***	***5,944***	***2,223***	***0,026***	***0,049***	***0,687***	***0,683***	***0,234***	***0,241***	***6,758***	***1,294***	***0,550***	***0,491***
tt		***0,284***		***0,501***		***0,406***		***0,354***		***0,576***		***0,426***		***0,183***		***0,081***		***0,858***		***0,107***
tinv		***1,301***		***0,764***		***0,963***		***1,093***		***0,625***		***0,919***		***1,722***		***2,586***		***0,195***		***2,281***
%		***>70%***		***NS***		***>50%***		***>60%***		***NS***		***>50%***		***>80%***		***>90%***		***NS***		***>80%***
Fall 1999																				
	9,646		6,801		4,212		30,704		10,476		0,153		1,066		0,694		8,672		1,148	
	4,595		14,655		7,402		17,780		19,753		0,081		1,212		0,766		12,759		1,125	
	9,386	12,885	15,437	16,287	7,514	10,993	10,921	15,939	12,264	10,557	0,072	0,088	1,022	1,593	0,389	0,838	6,558	7,545	6,816	1,538
	15,534	1,047	17,005	41,866	11,795	8,850	23,759	6,223	13,023	10,654	0,395	0,039	3,900	1,216	0,880	0,733	10,493	3,197	1,635	1,357
	5,595	3,756	16,129	3,005	9,756	2,548	15,798	7,310	15,242	7,041	0,001	0,120	1,718	0,523	0,561	2,021	7,388	4,476	1,354	1,120
	7,242	5,971	10,295	5,853	3,892	7,115	33,587	14,555	11,765	9,888	0,045	0,067	1,495	1,547	0,697	0,699	6,692	4,443	1,575	0,321
Ave.	***8,666***	***5,915***	***13,387***	***16,753***	***7,428***	***7,376***	***22,091***	***11,007***	***13,754***	***9,535***	***0,124***	***0,079***	***1,735***	***1,220***	***0,664***	***1,073***	***8,760***	***4,915***	***2,275***	***1,084***
SD	***3,916***	***5,065***	***3,984***	***17,689***	***3,077***	***3,589***	***8,856***	***4,948***	***3,336***	***1,697***	***0,142***	***0,034***	***1,093***	***0,494***	***0,171***	***0,635***	***2,450***	***1,851***	***2,234***	***0,537***
tt		***0,427***		***0,819***		***0,760***		***0,168***		***0,108***		***0,670***		***0,343***		***0,311***		***0,191***		***0,237***
tinv		***0,917***		***0,250***		***0,334***		***1,812***		***2,268***		***0,470***		***1,122***		***1,216***		***1,682***		***1,473***
%		***>50%***		***NS***		***NS***		***>80%***		***>80%***		***NS***		***>60%***		***>60%***		***>80%***		***>70%***

Table II-5 : Unbound minerals (mg/l) found in unlimed (N) and limed (K) roots at 50-60 cm depth in 1999.

Statistical Analysis Including: Ave. = Average, SD = Standard Deviation, tt = Student t-test, tinv = Inverse of t-test, % = Significant Difference, S = Significant, HS = Highly Significant, NS = Not Signficant.

Appendix 11B

Root Extracts Analyzed by UKS Merzalben, LUFA Speyer, 03.04.03

	Al N	Al K	Ca N	Ca K	Mg N	Mg K	K N	K K	Na N	Na K	Fe N	Fe K	Mn N	Mn K	P N	P K	S N	S K	Zn N	Zn K
Spring 2000																				
		6,321		3,261		4,763		19,069		9,487		0,015		0,682		0,561		7,441		0,447
	8,451	8,425	11,962	1,284	5,668	3,407	59,385	32,568	16,035	8,268	0,064	0,007	2,736	0,566	0,626	0,414	13,342	8,780	1,249	0,474
	9,668	0,928	6,668	2,124	2,983	2,617	27,082	14,430	11,678	8,592	0,064	0,043	0,878	0,349	0,671	0,267	8,298	1,606	3,561	0,540
	9,046	6,440	4,948	4,591	4,926	6,467	37,847	32,095	11,386	9,318	0,005	0,006	3,944	1,891	0,353	0,483	9,323	8,887	1,037	0,766
	3,767	1,120	4,053	0,930	3,032	1,741	34,141	39,331	9,769	7,439	0,013	0,005	1,049	0,407	0,600	0,276	6,372	2,677	0,808	0,248
	5,528	5,487	2,090	13,019	1,722	7,032	17,407	12,799	7,373	11,781	0,029	0,038	1,112	1,267	0,475	0,746	6,049	6,640	1,070	0,428
Ave.	***7,292***	***4,787***	***5,944***	***4,201***	***3,666***	***4,338***	***35,173***	***25,049***	***11,248***	***9,147***	***0,035***	***0,019***	***1,944***	***0,861***	***0,545***	***0,458***	***8,677***	***6,005***	***1,545***	***0,484***
SD	***2,530***	***3,071***	***3,747***	***4,524***	***1,600***	***2,124***	***15,617***	***11,034***	***3,175***	***1,489***	***0,028***	***0,017***	***1,347***	***0,602***	***0,130***	***0,182***	***2,939***	***3,127***	***1,138***	***0,169***
tt		***0,152***		***0,684***		***0,684***		***0,167***		***0,327***		***0,253***		***0,083***		***0,457***		***0,092***		***0,102***
tinv		***1,767***		***0,438***		***0,439***		***1,684***		***1,116***		***1,333***		***2,300***		***0,822***		***2,205***		***2,113***
%		***>80%***		***NS***		***NS***		***>80%***		***>60%***		***>70%***		***>90%***		***>50%***		***>90%***		***>80%***
Fall 2000																				
	10,174	2,573	6,790	3,090	3,447	5,285	51,170	30,042	16,827	9,010	0,385	0,003	1,165	0,400	5,928	0,562	20,128	6,049	0,909	0,319
	5,314	3,978	9,277	4,183	6,854	6,637	34,341	44,651	25,081	13,054	0,011	0,000	1,024	0,493	0,386	0,380	16,917	12,420	1,429	0,536
	3,294	8,936	3,424	3,863	2,180	10,423	36,982	33,522	15,612	14,035	0,013	0,014	0,415	0,601	0,376	0,605	6,906	13,972	0,815	0,365
	0,866	15,011	3,598	9,455	2,215	10,976	27,166	39,101	9,569	17,444	-0,011	0,059	0,894	2,673	0,184	1,060	1,963	13,713	1,075	0,730
	14,627	11,645	6,714	7,849	2,741	10,262	46,036	48,257	13,025	17,423	0,071	0,026	1,239	2,842	2,360	1,477	12,902	16,661	0,653	0,473
	2,649	6,907	3,519	5,012	1,796	5,013	41,465	29,016	10,624	12,635	0,015	0,018	1,095	2,411	0,761	0,661	7,655	12,163	0,681	0,625
	15,191	6,445	10,134	8,284	6,470	5,169	61,408	31,070	12,803	9,607	0,093	0,011	1,815	0,797	0,911	0,491	14,829	8,994	0,908	0,332
Ave.	***7,445***	***7,928***	***6,208***	***5,962***	***3,672***	***7,681***	***42,653***	***36,523***	***14,791***	***13,315***	***0,082***	***0,019***	***1,092***	***1,459***	***1,558***	***0,748***	***11,614***	***11,996***	***0,924***	***0,483***
SD	***5,875***	***4,330***	***2,805***	***2,513***	***2,111***	***2,748***	***11,389***	***7,610***	***5,202***	***3,348***	***0,138***	***0,020***	***0,419***	***1,651***	***2,060***	***0,386***	***6,372***	***3,493***	***0,266***	***0,157***
tt		***0,880***		***0,865***		***0,044***		***0,348***		***0,594***		***0,298***		***0,445***		***0,343***		***0,913***		***0,006***
tinv		***0,159***		***0,179***		***2,680***		***1,035***		***0,569***		***1,160***		***0,829***		***1,048***		***0,115***		***4,595***
%		***NS***		***NS***	***S***	***>95%***		***>60%***		***NS***		***>70%***		***>50%***		***>60%***		***NS***	***HS***	***>99%***

Table 11 -6 : Unbound minerals (mg/l) found in unlimed (N) and limed (K) roots at 50-60 cm depth in 2000.

Statistical Analysis Including: Ave. = Average, SD = Standard Deviation, tt = Student t-test, tinv = Inverse of t-test, % = Significant Difference, S = Significant, HS = Highly Significant, NS = Not Signficant.

Appendix 11C-1: Unbound Ca:Al, Ca:Mg, Ca:K Ratios in unlimed and limed soils at 0-10 cm depth.

0-10 cm	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
Table 1	Ca	Al	Ca/Al	Ca	Al	Ca/AL	Ca	Mg	Ca/Mg	Ca	Mg	Ca/Mg	Ca	K	Ca/K	Ca	K	Ca/K
Spring 1999																		
	36,316	1,899	19,121				36,316	16,654	2,181				36,316	26,895	1,350			
	13,685	11,965	1,144	81,895	1,107	73,949	13,685	6,941	1,972	81,895	34,570	2,369	13,685	18,312	0,747	81,895	26,058	3,143
	10,848	10,393	1,044	29,112	6,316	4,609	10,848	6,009	1,805	29,112	24,009	1,213	10,848	19,306	0,562	29,112	15,064	1,933
	8,744	12,699	0,689	29,559	3,546	8,337	8,744	3,930	2,225	29,559	28,094	1,052	8,744	16,415	0,533	29,559	15,859	1,864
	5,966	9,365	0,637	19,992	4,488	4,454	5,966	3,914	1,524	19,992	14,559	1,373	5,966	33,875	0,176	19,992	28,773	0,695
	4,785	0,915	5,230	35,452	2,965	11,958	4,785	4,374	1,094	35,452	17,034	2,081	4,785	48,289	0,099	35,452	9,180	3,862
Fall 1999																		
				33,883	6,606	5,129				33,883	24,951	1,358				33,883	84,168	0,403
	7,795	7,442	1,047	19,942	6,940	2,874	7,795	3,759	2,074	19,942	13,203	1,510	7,795	20,781	0,375	19,942	25,787	0,773
	3,730	6,118	0,610	13,340	8,719	1,530	3,730	2,033	1,835	13,340	8,884	1,502	3,730	18,212	0,205	13,340	26,855	0,497
	15,228	12,165	1,252	27,437	5,182	5,295	15,228	4,400	3,461	27,437	12,225	2,244	15,228	18,312	0,832	27,437	12,551	2,186
	19,693	11,296	1,743	21,992	9,310	2,362	19,693	6,796	2,898	21,992	20,870	1,054	19,693	25,151	0,783	21,992	19,876	1,106
	4,469	5,828	0,767	14,908	6,013	2,479	4,469	2,365	1,890	14,908	14,254	1,046	4,469	17,475	0,256	14,908	44,846	0,332
Spring 2000																		
	7,802	8,617	0,905	27,601	8,226	3,355	7,802	3,935	1,983	27,601	18,907	1,460	7,802	29,400	0,265	27,601	32,819	0,841
	3,031	7,516	0,403	30,504	4,067	7,500	3,031	1,718	1,764	30,504	13,415	2,274	3,031	32,490	0,093	30,504	23,213	1,314
	7,654	3,353	2,283	15,154	6,853	2,211	7,654	4,259	1,797	15,154	11,717	1,293	7,654	26,261	0,291	15,154	31,470	0,482
	7,788	9,456	0,824	39,530	5,981	6,609	7,788	3,346	2,328	39,530	14,775	2,676	7,788	20,200	0,386	39,530	23,912	1,653
	14,846	7,865	1,888	14,744	3,953	3,730	14,846	5,706	2,602	14,744	10,963	1,345	14,846	13,258	1,120	14,744	9,277	1,589
	36,557	8,624	4,239	23,938	4,491	5,330	36,557	11,681	3,130	23,938	14,179	1,688	36,557	26,993	1,354	23,938	15,711	1,524
Fall 2000																		
	52,075	1,581	32,932	20,332	3,645	5,579	52,075	18,264	2,851	20,332	10,324	1,969	52,075	13,587	3,833	20,332	14,583	1,394
	26,333	5,458	4,825	30,482	4,622	6,595	26,333	11,407	2,308	30,482	13,964	2,183	26,333	13,288	1,982	30,482	17,424	1,749
	17,562	7,508	2,339	61,179	4,079	14,999	17,562	6,248	2,811	61,179	20,296	3,014	17,562	19,475	0,902	61,179	46,610	1,313
	21,013	11,267	1,865	26,536	10,850	2,446	21,013	8,717	2,410	26,536	15,913	1,668	21,013	82,026	0,256	26,536	53,277	0,498
	13,378	8,053	1,661	25,224	9,395	2,685	13,378	4,335	3,086	25,224	11,352	2,222	13,378	13,810	0,969	25,224	13,685	1,843
	17,569	4,065	4,322	24,123	7,211	3,345	17,569	7,624	2,304	24,123	10,614	2,273	17,569	26,196	0,671	24,123	32,761	0,736
	27,097	2,434	11,132	38,024	7,888	4,821	27,097	10,811	2,506	38,024	20,570	1,849	27,097	45,414	0,597	38,024	58,371	0,651
	31,167	8,728	3,571	24,802	6,667	3,720	31,167	16,373	1,904	24,802	9,540	2,600	31,167	78,514	0,397	24,802	27,210	0,911
Average	16,605	7,384	4,259	29,187	5,965	7,836	16,605	7,024	2,270	29,187	16,367	1,813	16,605	28,157	0,761	29,187	28,374	1,332
tt						0,206						0,006						0,009
tinv-24						1,299						3,005						2,836
%						>70%						>99%						>99%

Appendix 11C-2: Unbound Ca:Na, Ca:Fe, Ca:Mn Ratios in unlimed and limed soils at 0-10 cm depth.

0-10 cm	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
Table 2	Ca	Na	Ca/Na	Ca	Na	Ca/Na	Ca	Fe	Ca/Fe	Ca	Fe	Ca/Fe	Ca	Mn	Ca/Mn	Ca	Mn	Ca/Mn
Spring 1999																		
	36,316	28,646	1,268				36,316	0,357	101,606				36,316	1,276	28,450			
	13,685	9,618	1,423	81,895	34,854	**2,350**	13,685	8,697	1,574	81,895	0,372	**219,918**	13,685	4,452	3,074	81,895	2,571	**31,853**
	10,848	8,001	1,356	29,112	16,330	**1,783**	10,848	6,080	1,784	29,112	4,830	**6,027**	10,848	5,154	2,105	29,112	5,865	**4,963**
	8,744	8,203	1,066	29,559	13,176	**2,243**	8,744	17,476	0,500	29,559	1,705	**17,336**	8,744	3,550	2,463	29,559	3,320	**8,904**
	5,966	9,915	0,602	19,992	18,303	**1,092**	5,966	2,512	2,375	19,992	0,695	**28,748**	5,966	1,195	4,994	19,992	2,615	**7,646**
	4,785	7,795	0,614	35,452	12,212	**2,903**	4,785	0,177	26,988	35,452	0,162	**218,787**	4,785	1,375	3,480	35,452	1,421	**24,953**
Fall 1999																		
				33,883	29,151	**1,162**				33,883	2,020	**16,777**				33,883	1,342	**25,242**
	7,795	8,825	0,883	19,942	12,652	**1,576**	7,795	0,800	9,744	19,942	0,670	**29,779**	7,795	1,397	5,581	19,942	1,982	**10,061**
	3,730	7,754	0,481	13,340	10,874	**1,227**	3,730	1,677	2,224	13,340	2,030	**6,572**	3,730	0,817	4,562	13,340	1,328	**10,046**
	15,228	11,187	1,361	27,437	17,434	**1,574**	15,228	2,948	5,165	27,437	0,204	**134,290**	15,228	2,634	5,781	27,437	0,418	**65,649**
	19,693	14,414	1,366	21,992	9,932	**2,214**	19,693	4,769	4,129	21,992	1,955	**11,246**	19,693	3,469	5,678	21,992	7,640	**2,879**
	4,469	8,559	0,522	14,908	12,939	**1,152**	4,469	1,131	3,952	14,908	0,468	**31,823**	4,469	0,812	5,503	14,908	2,716	**5,489**
Spring 2000																		
	7,802	9,101	0,857	27,601	17,463	**1,581**	7,802	0,262	29,751	27,601	0,480	**57,469**	7,802	3,170	2,461	27,601	2,531	**10,904**
	3,031	14,560	0,208	30,504	17,124	**1,781**	3,031	0,781	3,879	30,504	0,553	**55,175**	3,031	0,555	5,464	30,504	3,367	**9,059**
	7,654	12,438	0,615	15,154	16,340	**0,927**	7,654	0,099	77,399	15,154	0,569	**26,630**	7,654	1,447	5,290	15,154	2,376	**6,377**
	7,788	11,428	0,681	39,530	26,040	**1,518**	7,788	1,386	5,621	39,530	0,321	**123,139**	7,788	2,368	3,288	39,530	0,990	**39,917**
	14,846	12,144	1,222	14,744	10,263	**1,437**	14,846	5,814	2,553	14,744	2,635	**5,596**	14,846	0,707	20,988	14,744	2,263	**6,516**
	36,557	29,763	1,228	23,938	13,191	**1,815**	36,557	2,326	15,714	23,938	1,067	**22,435**	36,557	7,451	4,906	23,938	3,038	**7,880**
Fall 2000																		
	52,075	17,410	2,991	20,332	13,344	**1,524**	52,075	0,419	124,155	20,332	1,091	**18,630**	52,075	3,717	14,008	20,332	1,317	**15,435**
	26,333	13,265	1,985	30,482	14,124	**2,158**	26,333	1,516	17,373	30,482	0,572	**53,293**	26,333	3,354	7,851	30,482	1,750	**17,415**
	17,562	13,498	1,301	61,179	35,463	**1,725**	17,562	4,012	4,377	61,179	0,548	**111,616**	17,562	1,845	9,518	61,179	10,585	**5,780**
	21,013	22,383	0,939	26,536	23,565	**1,126**	21,013	2,308	9,106	26,536	0,658	**40,319**	21,013	3,343	6,285	26,536	5,470	**4,851**
	13,378	11,271	1,187	25,224	15,004	**1,681**	13,378	1,389	9,635	25,224	2,502	**10,082**	13,378	1,023	13,073	25,224	3,897	**6,473**
	17,569	20,341	0,864	24,123	20,043	**1,204**	17,569	0,238	73,678	24,123	0,481	**50,116**	17,569	0,804	21,854	24,123	3,042	**7,930**
	27,097	27,857	0,973	38,024	31,262	**1,216**	27,097	0,122	222,912	38,024	1,054	**36,075**	27,097	1,084	25,002	38,024	3,268	**11,634**
	31,167	32,892	0,948	24,802	28,622	**0,867**	31,167	0,326	95,491	24,802	0,771	**32,188**	31,167	5,845	5,332	24,802	3,388	**7,320**
Average	***16,605***	***14,851***	***1,078***	***29,187***	***18,788***	***1,593***	***16,605***	***2,705***	***34,067***	***29,187***	***1,137***	***54,563***	***16,605***	***2,514***	***8,680***	***29,187***	***3,140***	***14,207***
tt						**0,001**						**0,173**						**0,095**
tinv-24						**3,983**						**1,405**						**1,737**
%						**>99%**						**>80%**						**>90%**

Appendix 11C-3: Unbound Ca:P, Ca:S, Ca:Zn Ratios in unlimed and limed soils at 0-10 cm depth.

0-10 cm	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
Table 3	Ca	P	Ca/P	Ca	P	Ca/P	Ca	S	Ca/S	Ca	S	Ca/S	Ca	Zn	Ca/Zn	Ca	Zn	Ca/Zn
Spring 1999																		
	36,316	11,773	3,085				36,316	7,377	4,923				36,316	1,853	19,600			
	13,685	3,546	3,860	81,895	12,858	**6,369**	13,685	7,646	1,790	81,895	14,995	**5,461**	13,685	1,574	8,694	81,895	3,236	**25,311**
	10,848	4,390	2,471	29,112	4,798	**6,068**	10,848	6,706	1,618	29,112	11,695	**2,489**	10,848	1,252	8,664	29,112	2,433	**11,963**
	8,744	4,692	1,864	29,559	1,992	**14,836**	8,744	7,433	1,176	29,559	9,976	**2,963**	8,744	1,357	6,442	29,559	0,606	**48,791**
	5,966	10,325	0,578	19,992	3,660	**5,463**	5,966	8,727	0,684	19,992	9,922	**2,015**	5,966	0,799	7,466	19,992	2,469	**8,099**
	4,785	11,796	0,406	35,452	5,506	**6,439**	4,785	9,818	0,487	35,452	7,723	**4,590**	4,785	1,354	3,535	35,452	2,883	**12,296**
Fall 1999																		
				33,883	7,193	**4,711**				33,883	12,355	**2,742**				33,883	4,820	**7,030**
	7,795	5,801	1,344	19,942	3,238	**6,159**	7,795	7,428	1,049	19,942	11,175	**1,785**	7,795	0,968	8,051	19,942	1,119	**17,823**
	3,730	4,713	0,791	13,340	4,721	**2,826**	3,730	6,700	0,557	13,340	10,645	**1,253**	3,730	1,788	2,086	13,340	1,319	**10,117**
	15,228	7,014	2,171	27,437	2,901	**9,458**	15,228	7,798	1,953	27,437	5,000	**5,487**	15,228	3,273	4,653	27,437	1,957	**14,021**
	19,693	2,802	7,028	21,992	3,131	**7,025**	19,693	10,401	1,893	21,992	10,185	**2,159**	19,693	1,924	10,238	21,992	0,882	**24,945**
	4,469	4,016	1,113	14,908	4,830	**3,086**	4,469	9,766	0,458	14,908	9,037	**1,650**	4,469	1,932	2,314	14,908	0,712	**20,941**
Spring 2000																		
	7,802	3,747	2,082	27,601	4,392	**6,284**	7,802	8,048	0,969	27,601	8,129	**3,396**	7,802	0,725	10,760	27,601	1,396	**19,767**
	3,031	8,688	0,349	30,504	4,492	**6,790**	3,031	6,942	0,437	30,504	8,787	**3,472**	3,031	0,368	8,237	30,504	1,577	**19,349**
	7,654	12,369	0,619	15,154	3,906	**3,880**	7,654	8,403	0,911	15,154	15,542	**0,975**	7,654	1,218	6,285	15,154	0,875	**17,323**
	7,788	3,480	2,238	39,530	5,039	**7,845**	7,788	6,683	1,165	39,530	16,080	**2,458**	7,788	2,129	3,657	39,530	1,307	**30,248**
	14,846	6,687	2,220	14,744	2,193	**6,722**	14,846	7,306	2,032	14,744	5,418	**2,721**	14,846	1,627	9,123	14,744	0,799	**18,461**
	36,557	2,370	15,424	23,938	1,823	**13,132**	36,557	30,665	1,192	23,938	13,894	**1,723**	36,557	1,804	20,265	23,938	0,634	**37,752**
Fall 2000																		
	52,075	3,329	15,643	20,332	2,150	**9,459**	52,075	11,225	4,639	20,332	6,637	**3,063**	52,075	0,697	74,672	20,332	1,000	**20,327**
	26,333	1,794	14,675	30,482	2,232	**13,659**	26,333	8,406	3,133	30,482	7,913	**3,852**	26,333	0,584	45,061	30,482	0,859	**35,469**
	17,562	3,539	4,963	61,179	14,399	**4,249**	17,562	14,560	1,206	61,179	27,995	**2,185**	17,562	1,201	14,621	61,179	1,366	**44,799**
	21,013	8,785	2,392	26,536	7,095	**3,740**	21,013	18,850	1,115	26,536	19,773	**1,342**	21,013	1,401	15,000	26,536	1,432	**18,533**
	13,378	1,557	8,591	25,224	1,654	**15,246**	13,378	4,854	2,756	25,224	9,560	**2,639**	13,378	3,969	3,371	25,224	1,398	**18,048**
	17,569	10,569	1,662	24,123	2,406	**10,025**	17,569	12,994	1,352	24,123	14,660	**1,646**	17,569	1,043	16,844	24,123	1,034	**23,328**
	27,097	5,572	4,863	38,024	7,394	**5,143**	27,097	14,767	1,835	38,024	22,999	**1,653**	27,097	1,493	18,150	38,024	1,503	**25,300**
	31,167	12,765	2,442	24,802	5,149	**4,816**	31,167	25,013	1,246	24,802	8,433	**2,941**	31,167	1,311	23,770	24,802	1,171	**21,186**
Average	***16,605***	***6,245***	***4,115***	***29,187***	***4,766***	***7,337***	***16,605***	***10,741***	***1,623***	***29,187***	***11,941***	***2,666***	***16,605***	***1,506***	***14,062***	***29,187***	***1,551***	***22,049***
tt						**0,000**						**0,000**						**0,019**
tinv-24						**4,041**						**4,224**						**2,511**
%						**>99%**						**>99%**						**>98%**

Appendix 11C-4: Unbound Ca:Al, Ca:Mg, Ca:K Ratios in unlimed and limed soils at 30-40 cm depth.

30-40cm	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
Table 4	Ca	Al	**Ca/Al**	Ca	Al	**Ca/AL**	Ca	Mg	**Ca/Mg**	Ca	Mg	**Ca/Mg**	Ca	K	**Ca/K**	Ca	K	**Ca/K**
Spring 1999																		
	19,400	13,676	1,419				19,400	10,682	1,816				19,400	47,214	0,411			
	17,219	5,552	3,101				17,219	7,765	2,217				17,219	23,334	0,738			
	4,365	7,278	0,600				4,365	2,406	1,815				4,365	12,499	0,349			
	10,146	6,502	1,560	29,916	5,792	**5,165**	10,146	6,828	1,486	29,916	25,085	**1,193**	10,146	11,615	0,874	29,916	57,832	**0,517**
	4,965	4,878	1,018	39,303	21,284	**1,847**	4,965	3,116	1,593	39,303	38,557	**1,019**	4,965	33,746	0,147	39,303	49,772	**0,790**
Fall 1999																		
	13,452	8,575	1,569				13,452	7,556	1,780				13,452	40,400	0,333			
	2,283	0,370	6,166				2,283	0,571	3,999				2,283	1,485	1,537			
	39,869	7,274	5,481				39,869	21,616	1,844				39,869	39,971	0,997			
	10,880	19,921	0,546				10,880	8,347	1,303				10,880	55,259	0,197			
	20,740	12,492	1,660	7,110	7,911	**0,899**	20,740	5,018	4,133	7,110	7,657	**0,929**	20,740	14,587	1,422	7,110	20,328	**0,350**
	13,365	8,951	1,493	14,318	14,096	**1,016**	13,365	5,290	2,527	14,318	17,355	**0,825**	13,365	43,470	0,307	14,318	39,448	**0,363**
	8,883	10,544	0,843	6,567	9,100	**0,722**	8,883	2,202	4,035	6,567	7,438	**0,883**	8,883	17,635	0,504	6,567	21,379	**0,307**
Spring 2000																		
	2,366	6,919	0,342	3,369	7,094	**0,475**	2,366	1,917	1,234	3,369	8,956	**0,376**	2,366	30,157	0,078	3,369	20,390	**0,165**
	0,689	2,445	0,282	2,272	9,619	**0,236**	0,689	0,530	1,300	2,272	4,544	**0,500**	0,689	32,742	0,021	2,272	26,564	**0,086**
	6,537	8,136	0,803	3,106	8,138	**0,382**	6,537	3,960	1,651	3,106	8,054	**0,386**	6,537	17,233	0,379	3,106	29,701	**0,105**
	5,382	4,659	1,155	10,174	8,612	**1,181**	5,382	9,705	0,555	10,174	13,486	**0,754**	5,382	25,527	0,211	10,174	15,733	**0,647**
	1,214	3,185	0,381	1,337	2,014	**0,664**	1,214	1,646	0,738	1,337	4,684	**0,285**	1,214	49,007	0,025	1,337	40,483	**0,033**
	16,277	4,532	3,591	13,565	5,474	**2,478**	16,277	7,851	2,073	13,565	9,991	**1,358**	16,277	13,316	1,222	13,565	12,697	**1,068**
Fall 2000																		
	98,882	0,264	374,554	7,354	7,129	**1,032**	98,882	45,043	2,195	7,354	9,857	**0,746**	98,882	62,184	1,590	7,354	33,363	**0,220**
	13,116	10,837	1,210	1,687	4,032	**0,418**	13,116	7,253	1,808	1,687	2,994	**0,563**	13,116	38,890	0,337	1,687	27,069	**0,062**
	2,312	3,717	0,622	4,013	2,296	**1,748**	2,312	2,012	1,149	4,013	4,199	**0,956**	2,312	42,459	0,054	4,013	21,789	**0,184**
	21,047	9,609	2,190	15,133	14,654	**1,033**	21,047	8,491	2,479	15,133	12,613	**1,200**	21,047	26,469	0,795	15,133	42,011	**0,360**
	3,397	9,187	0,370	14,768	16,707	**0,884**	3,397	1,907	1,781	14,768	13,729	**1,076**	3,397	30,508	0,111	14,768	25,243	**0,585**
	11,451	2,676	4,279	8,661	2,370	**3,654**	11,451	4,611	2,483	8,661	6,843	**1,266**	11,451	34,875	0,328	8,661	14,488	**0,598**
	26,819	13,884	1,932	8,599	7,065	**1,217**	26,819	12,995	2,064	8,599	6,169	**1,394**	26,819	68,444	0,392	8,599	25,611	**0,336**
Average	***15,002***	***7,443***	***16,687***	***10,625***	***8,522***	***1,392***	***15,002***	***7,573***	***2,002***	***10,625***	***11,234***	***0,873***	***15,002***	***32,521***	***0,534***	***10,625***	***29,106***	***0,376***
tt						***0,332***						***0,000***						***0,354***
tinv-15						***1,003***						***5,341***						***0,956***
%						**>60%**						**>99%**						**>60%**

Appendix 11C-5: Unbound Ca:Na, Ca:Fe, Ca:Mn Ratios in unlimed and limed soils at 30-40 cm depth.

30-40cm	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
Table 5	Ca	Na	Ca/Na	Ca	Na	Ca/Na	Ca	Fe	Ca/Fe	Ca	Fe	Ca/Fe	Ca	Mn	Ca/Mn	Ca	Mn	Ca/Mn
Spring 1999																		
	19,400	18,613	1,042				19,400	0,065	297,685				19,400	1,885	10,291			
	17,219	15,054	1,144				17,219	0,024	728,986				17,219	1,677	10,265			
	4,365	8,775	0,497				4,365	0,048	91,188				4,365	2,786	1,567			
	10,146	9,941	1,021	29,916	34,829	**0,859**	10,146	0,015	687,879	29,916	0,060	**498,765**	10,146	2,870	3,535	29,916	1,354	**22,099**
	4,965	8,486	0,585	39,303	40,178	**0,978**	4,965	0,203	24,491	39,303	0,127	**309,886**	4,965	0,286	17,374	39,303	2,658	**14,784**
Fall 1999																		
	13,452	16,305	0,825				13,452	0,031	434,920				13,452	1,861	7,227			
	2,283	5,272	0,433				2,283	0,048	47,321				2,283	0,112	20,357			
	39,869	48,460	0,823				39,869	0,144	277,387				39,869	2,420	16,474			
	10,880	10,307	1,056				10,880	0,142	76,673				10,880	4,124	2,638			
	20,740	15,607	1,329	7,110	10,146	**0,701**	20,740	0,096	216,829	7,110	0,044	**162,058**	20,740	2,735	7,584	7,110	0,729	**9,748**
	13,365	11,467	1,166	14,318	11,028	**1,298**	13,365	0,074	181,518	14,318	0,098	**146,040**	13,365	1,817	7,355	14,318	6,141	**2,332**
	8,883	7,777	1,142	6,567	13,307	**0,493**	8,883	0,059	151,439	6,567	0,007	**984,511**	8,883	2,448	3,628	6,567	1,597	**4,111**
Spring 2000																		
	2,366	11,149	0,212	3,369	12,768	**0,264**	2,366	0,009	252,762	3,369	0,076	**44,506**	2,366	2,049	1,154	3,369	1,118	**3,014**
	0,689	6,841	0,101	2,272	10,930	**0,208**	0,689	0,254	2,713	2,272	0,024	**96,499**	0,689	0,228	3,019	2,272	0,667	**3,407**
	6,537	11,248	0,581	3,106	13,964	**0,222**	6,537	0,031	211,342	3,106	0,018	**170,954**	6,537	1,532	4,268	3,106	1,164	**2,669**
	5,382	13,241	0,406	10,174	10,235	**0,994**	5,382	0,039	137,972	10,174	0,073	**139,979**	5,382	1,493	3,605	10,174	4,126	**2,465**
	1,214	8,296	0,146	1,337	9,196	**0,145**	1,214	0,028	43,592	1,337	0,010	**132,127**	1,214	0,535	2,267	1,337	0,665	**2,011**
	16,277	18,834	0,864	13,565	19,421	**0,698**	16,277	0,047	348,397	13,565	0,099	**136,891**	16,277	2,979	5,465	13,565	0,972	**13,954**
Fall 2000																		
	98,882	27,102	3,648	7,354	18,131	**0,406**	98,882	0,032	3082,363	7,354	0,014	**541,923**	98,882	13,296	7,437	7,354	0,813	**9,047**
	13,116	24,671	0,532	1,687	10,269	**0,164**	13,116	0,014	963,721	1,687	0,022	**77,983**	13,116	1,753	7,481	1,687	0,394	**4,284**
	2,312	9,811	0,236	4,013	10,977	**0,366**	2,312	0,032	72,059	4,013	0,017	**235,761**	2,312	0,757	3,052	4,013	0,550	**7,298**
	21,047	19,622	1,073	15,133	21,792	**0,694**	21,047	0,086	244,909	15,133	0,035	**431,767**	21,047	0,947	22,214	15,133	1,728	**8,760**
	3,397	11,803	0,288	14,768	16,134	**0,915**	3,397	0,021	165,454	14,768	0,050	**297,510**	3,397	2,498	1,360	14,768	2,708	**5,453**
	11,451	19,948	0,574	8,661	9,970	**0,869**	11,451	0,404	28,362	8,661	0,021	**407,949**	11,451	0,222	51,658	8,661	3,175	**2,728**
	26,819	23,342	1,149	8,599	17,803	**0,483**	26,819	0,013	2090,34	8,599	0,037	**233,475**	26,819	2,898	9,255	8,599	1,140	**7,542**
Average	***15,002***	***15,279***	***0,835***	***10,625***	***16,171***	***0,598***	***15,002***	***0,078***	***434,412***	***10,625***	***0,046***	***280,477***	***15,002***	***2,248***	***9,221***	***10,625***	***1,761***	***6,984***
tt						***0,249***						***0,274***						***0,532***
tinv-15						***1,198***						***1,135***						***0,639***
%						**>70%**						**>70%**						**NS**

Appendix 11C-6: Unbound Ca:P, Ca:S, Ca:Zn Ratios in unlimed and limed soils at 30-40 cm depth.

30-40 cm	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
Table 6	Ca	P	**Ca/P**	Ca	P	**Ca/P**	Ca	S	**Ca/S**	Ca	S	**Ca/S**	Ca	Zn	**Ca/Zn**	Ca	Zn	**Ca/Zn**
Spring 1999																		
	19,400	1,149	16,886				19,400	16,093	1,206				19,400	0,892	21,751			
	17,219	0,461	37,339				17,219	4,551	3,784				17,219	0,824	20,892			
	4,365	0,459	9,503				4,365	3,253	1,342				4,365	0,403	10,832			
	10,146	1,119	9,064	29,916	0,666	**44,890**	10,146	5,207	1,948	29,916	27,042	**1,106**	10,146	0,546	18,577	29,916	0,749	**39,960**
	4,965	5,573	0,891	39,303	0,713	**55,145**	4,965	5,365	0,925	39,303	27,370	**1,436**	4,965	0,533	9,308	39,303	2,051	**19,164**
Fall 1999																		
	13,452	0,911	14,767				13,452	12,137	1,108				13,452	0,749	17,966			
	2,283	1,063	2,148				2,283	1,517	1,505				2,283	0,508	4,491			
	39,869	0,536	74,448				39,869	37,408	1,066				39,869	5,685	7,014			
	10,880	1,502	7,244				10,880	10,097	1,077				10,880	2,741	3,969			
	20,740	0,331	62,686	7,110	0,543	**13,094**	20,740	5,317	3,901	7,110	6,536	**1,088**	20,740	0,959	21,623	7,110	0,378	**18,790**
	13,365	0,877	15,239	14,318	0,535	**26,762**	13,365	8,344	1,602	14,318	11,310	**1,266**	13,365	1,002	13,344	14,318	0,848	**16,887**
	8,883	0,483	18,408	6,567	0,645	**10,180**	8,883	5,316	1,671	6,567	9,616	**0,683**	8,883	1,119	7,942	6,567	0,446	**14,717**
Spring 2000																		
	2,366	0,309	7,646	3,369	5,810	**0,580**	2,366	7,593	0,312	3,369	9,032	**0,373**	2,366	0,417	5,679	3,369	0,494	**6,817**
	0,689	3,245	0,212	2,272	0,515	**4,409**	0,689	4,606	0,150	2,272	8,872	**0,256**	0,689	0,521	1,323	2,272	0,531	**4,281**
	6,537	0,433	15,104	3,106	0,958	**3,243**	6,537	5,039	1,297	3,106	11,741	**0,265**	6,537	0,521	12,554	3,106	0,429	**7,234**
	5,382	0,350	15,368	10,174	1,083	**9,397**	5,382	6,719	0,801	10,174	6,702	**1,518**	5,382	0,418	12,891	10,174	0,459	**22,160**
	1,214	0,213	5,703	1,337	0,220	**6,078**	1,214	6,719	0,181	1,337	6,375	**0,210**	1,214	0,248	4,893	1,337	0,111	**12,101**
	16,277	0,439	37,107	13,565	0,392	**34,630**	16,277	16,712	0,974	13,565	17,107	**0,793**	16,277	0,780	20,880	13,565	0,428	**31,665**
Fall 2000																		
	98,882	12,165	8,128	7,354	0,349	**21,072**	98,882	25,932	3,813	7,354	16,257	**0,452**	98,882	1,145	86,397	7,354	0,526	**13,987**
	13,116	0,463	28,336	1,687	0,420	**4,018**	13,116	18,693	0,702	1,687	9,669	**0,174**	13,116	1,030	12,731	1,687	0,181	**9,295**
	2,312	0,227	10,196	4,013	0,497	**8,070**	2,312	7,423	0,311	4,013	4,835	**0,830**	2,312	0,575	4,021	4,013	0,184	**21,822**
	21,047	0,789	26,686	15,133	0,762	**19,872**	21,047	14,521	1,449	15,133	18,437	**0,821**	21,047	0,753	27,944	15,133	0,566	**26,756**
	3,397	1,516	2,241	14,768	0,895	**16,497**	3,397	11,603	0,293	14,768	10,160	**1,454**	3,397	1,059	3,208	14,768	0,544	**27,133**
	11,451	0,266	43,039	8,661	0,598	**14,494**	11,451	7,152	1,601	8,661	6,650	**1,302**	11,451	0,499	22,950	8,661	0,194	**44,540**
	26,819	1,008	26,595	8,599	0,792	**10,860**	26,819	23,642	1,134	8,599	10,714	**0,803**	26,819	0,849	31,585	8,599	0,265	**32,394**
Average	***15,002***	***1,435***	***19,799***	***10,625***	***0,911***	***16,850***	***15,002***	***10,838***	***1,366***	***10,625***	***12,135***	***0,824***	***15,002***	***0,991***	***16,191***	***10,625***	***0,521***	***20,539***
tt						***0,769***						***0,103***						***0,565***
tinv-15						***0,299***						***1,735***						***0,588***
%						**NS**						**>80%**						**NS**

Appendix 11C-7: Unbound Ca:Al, Ca:Mg, Ca:K Ratios in unlimed and limed soils at 50-60 cm depth.

50-60cm	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
Table 7	Ca	Al	Ca/Al	Ca	Al	Ca/AL	Ca	Mg	Ca/Mg	Ca	Mg	Ca/Mg	Ca	K	Ca/K	Ca	K	Ca/K
Spring 1999																		
				14,154	4,906	2,885				14,154	11,687	1,211				14,154	34,557	0,410
				32,487	5,911	5,496				32,487	11,458	2,835				32,487	14,388	2,258
				19,321	8,092	2,388				19,321	10,347	1,867				19,321	11,821	1,634
	29,613	8,294	3,570	17,396	4,756	3,657	29,613	12,558	2,358	17,396	7,313	2,379	29,613	33,936	0,873	17,396	12,900	1,349
	9,165	3,847	2,382	27,501	5,330	5,160	9,165	3,769	2,432	27,501	13,211	2,082	9,165	11,068	0,828	27,501	20,903	1,316
	7,533	3,878	1,942	26,999	3,097	8,719	7,533	1,674	4,500	26,999	7,519	3,591	7,533	8,527	0,883	26,999	9,002	2,999
	8,831	15,853	0,557	7,012	6,377	1,100	8,831	5,422	1,629	7,012	7,485	0,937	8,831	63,499	0,139	7,012	34,861	0,201
Fall 1999																		
	6,801	9,646	0,705				6,801	4,212	1,615				6,801	30,704	0,221			
	14,655	4,595	3,189				14,655	7,402	1,980				14,655	17,780	0,824			
	15,437	9,386	1,645	16,287	12,885	1,264	15,437	7,514	2,054	16,287	10,993	1,482	15,437	10,921	1,414	16,287	15,939	1,022
	17,005	15,534	1,095	41,866	1,047	39,999	17,005	11,795	1,442	41,866	8,850	4,730	17,005	23,759	0,716	41,866	6,223	6,727
	16,129	5,595	2,883	3,005	3,756	0,800	16,129	9,756	1,653	3,005	2,548	1,179	16,129	15,798	1,021	3,005	7,310	0,411
	10,295	7,242	1,422	5,853	5,971	0,980	10,295	3,892	2,645	5,853	7,115	0,823	10,295	33,587	0,307	5,853	14,555	0,402
Spring 2000																		
				3,261	6,321	0,516				3,261	4,763	0,685				3,261	19,069	0,171
	11,962	8,451	1,415	1,284	8,425	0,152	11,962	5,668	2,110	1,284	3,407	0,377	11,962	59,385	0,201	1,284	32,568	0,039
	6,668	9,668	0,690	2,124	0,928	2,288	6,668	2,983	2,236	2,124	2,617	0,812	6,668	27,082	0,246	2,124	14,430	0,147
	4,948	9,046	0,547	4,591	6,440	0,713	4,948	4,926	1,004	4,591	6,467	0,710	4,948	37,847	0,131	4,591	32,095	0,143
	4,053	3,767	1,076	0,930	1,120	0,830	4,053	3,032	1,337	0,930	1,741	0,534	4,053	34,141	0,119	0,930	39,331	0,024
	2,090	5,528	0,378	13,019	5,487	2,373	2,090	1,722	1,213	13,019	7,032	1,851	2,090	17,407	0,120	13,019	12,799	1,017
Fall 2000																		
	6,790	10,174	0,667	3,090	2,573	1,201	6,790	3,447	1,970	3,090	5,285	0,585	6,790	51,170	0,133	3,090	30,042	0,103
	9,277	5,314	1,746	4,183	3,978	1,052	9,277	6,854	1,354	4,183	6,637	0,630	9,277	34,341	0,270	4,183	44,651	0,094
	3,424	3,294	1,039	3,863	8,936	0,432	3,424	2,180	1,571	3,863	10,423	0,371	3,424	36,982	0,093	3,863	33,522	0,115
	3,598	0,866	4,156	9,455	15,011	0,630	3,598	2,215	1,625	9,455	10,976	0,861	3,598	27,166	0,132	9,455	39,101	0,242
	6,714	14,627	0,459	7,849	11,645	0,674	6,714	2,741	2,450	7,849	10,262	0,765	6,714	46,036	0,146	7,849	48,257	0,163
	3,519	2,649	1,328	5,012	6,907	0,726	3,519	1,796	1,959	5,012	5,013	1,000	3,519	41,465	0,085	5,012	29,016	0,173
	10,134	15,191	0,667	8,284	6,445	1,285	10,134	6,470	1,566	8,284	5,169	1,603	10,134	61,408	0,165	8,284	31,070	0,267
Average	9,484	7,838	1,525	11,618	6,098	3,555	9,484	5,092	1,941	11,618	7,430	1,412	9,484	32,910	0,412	11,618	24,517	0,893
tt						0,2775						0,028						0,177
tinv-24						1,1112						2,332						1,391
%						>70%						>95%						>80%

Appendix 11C-8: Unbound Ca:Na, Ca:Fe, Ca:Mn Ratios in unlimed and limed soils at 50-60 cm depth.

50-60 cm	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
Table 8	Ca	Na	**Ca/Na**	Ca	Na	**Ca/Na**	Ca	Fe	**Ca/Fe**	Ca	Fe	**Ca/Fe**	Ca	Mn	**Ca/Mn**	Ca	Mn	**Ca/Mn**
Spring 1999																		
				14,154	14,702	**0,963**				14,154	0,028	**505,515**				14,154	0,740	**19,129**
				32,487	14,050	**2,312**				32,487	0,169	**192,778**				32,487	1,370	**23,720**
				19,321	11,300	**1,710**				19,321	0,081	**238,593**				19,321	1,478	**13,074**
	29,613	20,713	1,430	17,396	10,808	**1,610**	29,613	0,050	596,802	17,396	0,093	**186,797**	29,613	1,938	15,279	17,396	1,803	**9,647**
	9,165	9,589	0,956	27,501	12,959	**2,122**	9,165	0,015	591,669	27,501	0,073	**374,474**	9,165	1,427	6,424	27,501	2,773	**9,918**
	7,533	9,270	0,813	26,999	14,935	**1,808**	7,533	0,080	94,396	26,999	0,026	**1053,01**	7,533	0,551	13,682	26,999	0,937	**28,814**
	8,831	18,493	0,478	7,012	9,042	**0,775**	8,831	0,055	160,338	7,012	0,104	**67,174**	8,831	0,546	16,174	7,012	1,061	**6,606**
Fall 1999																		
	6,801	10,476	0,649				6,801	0,153	44,509				6,801	1,066	6,380			
	14,655	19,753	0,742				14,655	0,081	181,303				14,655	1,212	12,089			
	15,437	12,264	1,259	16,287	10,557	**1,543**	15,437	0,072	214,729	16,287	0,088	**184,161**	15,437	1,022	15,108	16,287	1,593	**10,225**
	17,005	13,023	1,306	41,866	10,654	**3,930**	17,005	0,395	43,085	41,866	0,039	**1080,42**	17,005	3,900	4,361	41,866	1,216	**34,429**
	16,129	15,242	1,058	3,005	7,041	**0,427**	16,129	0,001	31018,1	3,005	0,120	**24,973**	16,129	1,718	9,390	3,005	0,523	**5,744**
	10,295	11,765	0,875	5,853	9,888	**0,592**	10,295	0,045	229,441	5,853	0,067	**87,050**	10,295	1,495	6,888	5,853	1,547	**3,785**
Spring 2000																		
				3,261	9,487	**0,344**				3,261	0,015	**211,176**				3,261	0,682	**4,779**
	11,962	16,035	0,746	1,284	8,268	**0,155**	11,962	0,064	187,662	1,284	0,007	**178,288**	11,962	2,736	4,372	1,284	0,566	**2,266**
	6,668	11,678	0,571	2,124	8,592	**0,247**	6,668	0,064	104,668	2,124	0,043	**49,507**	6,668	0,878	7,597	2,124	0,349	**6,079**
	4,948	11,386	0,435	4,591	9,318	**0,493**	4,948	0,005	949,656	4,591	0,006	**815,497**	4,948	3,944	1,255	4,591	1,891	**2,428**
	4,053	9,769	0,415	0,930	7,439	**0,125**	4,053	0,013	319,632	0,930	0,005	**192,099**	4,053	1,049	3,864	0,930	0,407	**2,283**
	2,090	7,373	0,283	13,019	11,781	**1,105**	2,090	0,029	71,653	13,019	0,038	**344,325**	2,090	1,112	1,879	13,019	1,267	**10,277**
Fall 2000																		
	6,790	16,827	0,404	3,090	9,010	**0,343**	6,790	0,385	17,649	3,090	0,003	**944,933**	6,790	1,165	5,829	3,090	0,400	**7,719**
	9,277	25,081	0,370	4,183	13,054	**0,320**	9,277	0,011	864,607	4,183	0,000	**944,933**	9,277	1,024	9,063	4,183	0,493	**8,483**
	3,424	15,612	0,219	3,863	14,035	**0,275**	3,424	0,013	269,811	3,863	0,014	**278,499**	3,424	0,415	8,242	3,863	0,601	**6,424**
	3,598	9,569	0,376	9,455	17,444	**0,542**	3,598	-0,011	-341,08	9,455	0,059	**160,203**	3,598	0,894	4,024	9,455	2,673	**3,538**
	6,714	13,025	0,515	7,849	17,423	**0,451**	6,714	0,071	94,862	7,849	0,026	**301,544**	6,714	1,239	5,419	7,849	2,842	**2,762**
	3,519	10,624	0,331	5,012	12,635	**0,397**	3,519	0,015	240,187	5,012	0,018	**275,840**	3,519	1,095	3,213	5,012	2,411	**2,079**
	10,134	12,803	0,792	8,284	9,607	**0,862**	10,134	0,093	109,260	8,284	0,011	**772,075**	10,134	1,815	5,584	8,284	0,797	**10,401**
Average	9,484	13,653	0,683	11,618	11,418	**0,977**	9,484	0,077	1639,22	11,618	0,047	**394,328**	9,484	1,465	7,551	11,618	1,268	**9,775**
tt						**0,186**						**0,389**						**0,502**
tinv-24						**1,362**						**0,877**						**0,681**
%						**>80%**						**>60%**						**NS**

Appendix 11C-9: Unbound Ca:P, Ca:S, Ca:Zn Ratios in unlimed and limed soils at 50-60 cm depth.

50-60cm	Unlimed			Limed			Unlimed			Limed			Unlimed			Limed		
Table 9	Ca	P	**Ca/P**	Ca	P	**Ca/P**	Ca	S	**Ca/S**	Ca	S	**Ca/S**	Ca	Zn	**Ca/Zn**	Ca	Zn	**Ca/Zn**
Spring 1999																		
				14,154	0,672	**21,067**				14,154	6,959	**2,034**				14,154	0,605	**23,400**
				32,487	1,284	**25,304**				32,487	8,888	**3,655**				32,487	0,550	**59,046**
				19,321	0,712	**27,151**				19,321	7,548	**2,560**				19,321	0,429	**45,027**
	29,613	0,526	56,329	17,396	1,050	**16,573**	29,613	12,060	2,455	17,396	7,161	**2,429**	29,613	1,412	20,975	17,396	1,528	**11,382**
	9,165	0,806	11,366	27,501	0,841	**32,715**	9,165	5,897	1,554	27,501	9,463	**2,906**	9,165	2,093	4,380	27,501	1,406	**19,562**
	7,533	0,432	17,423	26,999	0,615	**43,878**	7,533	2,944	2,558	26,999	10,385	**2,600**	7,533	0,751	10,030	26,999	0,259	**104,429**
	8,831	0,243	36,275	7,012	0,731	**9,597**	8,831	18,148	0,487	7,012	9,080	**0,772**	8,831	1,530	5,774	7,012	0,946	**7,412**
Fall 1999																		
	6,801	0,694	9,793				6,801	8,672	0,784				6,801	1,148	5,922			
	14,655	0,766	19,138				14,655	12,759	1,149				14,655	1,125	13,027			
	15,437	0,389	39,732	16,287	0,838	**19,444**	15,437	6,558	2,354	16,287	7,545	**2,159**	15,437	6,816	2,265	16,287	1,538	**10,593**
	17,005	0,880	19,328	41,866	0,733	**57,150**	17,005	10,493	1,621	41,866	3,197	**13,095**	17,005	1,635	10,401	41,866	1,357	**30,859**
	16,129	0,561	28,757	3,005	2,021	**1,487**	16,129	7,388	2,183	3,005	4,476	**0,671**	16,129	1,354	11,914	3,005	1,120	**2,683**
	10,295	0,697	14,770	5,853	0,699	**8,378**	10,295	6,692	1,538	5,853	4,443	**1,317**	10,295	1,575	6,538	5,853	0,321	**18,235**
Spring 2000																		
				3,261	0,561	**5,813**				3,261	7,441	**0,438**				3,261	0,447	**7,296**
	11,962	0,626	19,099	1,284	0,414	**3,098**	11,962	13,342	0,897	1,284	8,780	**0,146**	11,962	1,249	9,575	1,284	0,474	**2,706**
	6,668	0,671	9,931	2,124	0,267	**7,958**	6,668	8,298	0,804	2,124	1,606	**1,323**	6,668	3,561	1,872	2,124	0,540	**3,931**
	4,948	0,353	14,034	4,591	0,483	**9,514**	4,948	9,323	0,531	4,591	8,887	**0,517**	4,948	1,037	4,770	4,591	0,766	**5,991**
	4,053	0,600	6,755	0,930	0,276	**3,367**	4,053	6,372	0,636	0,930	2,677	**0,347**	4,053	0,808	5,015	0,930	0,248	**3,753**
	2,090	0,475	4,396	13,019	0,746	**17,458**	2,090	6,049	0,346	13,019	6,640	**1,961**	2,090	1,070	1,954	13,019	0,428	**30,406**
Fall 2000																		
	6,790	5,928	1,145	3,090	0,562	**5,501**	6,790	20,128	0,337	3,090	6,049	**0,511**	6,790	0,909	7,470	3,090	0,319	**9,679**
	9,277	0,386	24,045	4,183	0,380	**11,022**	9,277	16,917	0,548	4,183	12,420	**0,337**	9,277	1,429	6,490	4,183	0,536	**7,802**
	3,424	0,376	9,111	3,863	0,605	**6,382**	3,424	6,906	0,496	3,863	13,972	**0,276**	3,424	0,815	4,200	3,863	0,365	**10,585**
	3,598	0,184	19,583	9,455	1,060	**8,921**	3,598	1,963	1,833	9,455	13,713	**0,690**	3,598	1,075	3,347	9,455	0,730	**12,954**
	6,714	2,360	2,845	7,849	1,477	**5,316**	6,714	12,902	0,520	7,849	16,661	**0,471**	6,714	0,653	10,276	7,849	0,473	**16,592**
	3,519	0,761	4,621	5,012	0,661	**7,582**	3,519	7,655	0,460	5,012	12,163	**0,412**	3,519	0,681	5,168	5,012	0,625	**8,019**
	10,134	0,911	11,129	8,284	0,491	**16,874**	10,134	14,829	0,683	8,284	8,994	**0,921**	10,134	0,908	11,161	8,284	0,332	**24,942**
Average	9,484	0,892	17,255	11,618	0,757	**15,481**	9,484	9,832	1,126	11,618	8,298	**1,773**	9,484	1,529	7,387	11,618	0,681	**19,887**
tt						**0,496**						**0,367**						**0,058**
tinv-24						**0,692**						**0,920**						**1,994**
%						**>50%**						**>60%**						**>80%**

Appendix 11D

Table 11D-1: % Significant differences of Unbound minerals with respect to soil depths 0-10, 30-40 and 50-60 cm. NS= Not Signficant Spring 1999

Spring 1999	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
0-10	1,899		36,316		16,654		26,895		28,646		0,357		1,276		11,773		7,377		1,853	
	11,965	1,107	13,685	81,895	6,941	34,570	18,312	26,058	9,618	34,854	8,697	0,372	4,452	2,571	3,546	12,858	7,646	14,995	1,574	3,236
	10,393	6,316	10,848	29,112	6,009	24,009	19,306	15,064	8,001	16,330	6,080	4,830	5,154	5,865	4,390	4,798	6,706	11,695	1,252	2,433
	12,699	3,546	8,744	29,559	3,930	28,094	16,415	15,859	8,203	13,176	17,476	1,705	3,550	3,320	4,692	1,992	7,433	9,976	1,357	0,606
	9,365	4,488	5,966	19,992	3,914	14,559	33,875	28,773	9,915	18,303	2,512	0,695	1,195	2,615	10,325	3,660	8,727	9,922	0,799	2,469
	0,915	2,965	4,785	35,452	4,374	17,034	48,289	9,180	7,795	12,212	0,177	0,162	1,375	1,421	11,796	5,506	9,818	7,723	1,354	2,883
30-40	13,676		19,400		10,682		47,214		18,613		0,065		1,885		1,149		16,093		0,892	
	5,552		17,219		7,765		23,334		15,054		0,024		1,677		0,461		4,551		0,824	
	7,278		4,365		2,406		12,499		8,775		0,048		2,786		0,459		3,253		0,403	
	6,502	5,792	10,146	29,916	6,828	25,085	11,615	57,832	9,941	34,829	0,015	0,060	2,870	1,354	1,119	0,666	5,207	27,042	0,546	0,749
	4,878	21,284	4,965	39,303	3,116	38,557	33,746	49,772	8,486	40,178	0,203	0,127	0,286	2,658	5,573	0,713	5,365	27,370	0,533	2,051
50-60		4,906		14,154		11,687		34,557		14,702		0,028		0,740		0,672		6,959		0,605
		5,911		32,487		11,458		14,388		14,050		0,169		1,370		1,284		8,888		0,550
		8,092		19,321		10,347		11,821		11,300		0,081		1,478		0,712		7,548		0,429
	8,294	4,756	29,613	17,396	12,558	7,313	33,936	12,900	20,713	10,808	0,050	0,093	1,938	1,803	0,526	1,050	12,060	7,161	1,412	1,528
	3,847	5,330	9,165	27,501	3,769	13,211	11,068	20,903	9,589	12,959	0,015	0,073	1,427	2,773	0,806	0,841	5,897	9,463	2,093	1,406
	3,878	3,097	7,533	26,999	1,674	7,519	8,527	9,002	9,270	14,935	0,080	0,026	0,551	0,937	0,432	0,615	2,944	10,385	0,751	0,259
	15,853	6,377	8,831	7,012	5,422	7,485	63,499	34,861	18,493	9,042	0,055	0,104	0,546	1,061	0,243	0,731	18,148	9,080	1,530	0,946
0-10/30-40																				
tt	0,466	0,455	0,296	0,264	0,354	0,210	0,869	0,104	0,140	0,160	0,083	0,465	0,231	0,994	0,011	0,145	0,656	0,044	0,008	0,213
tinv-4	0,805	0,827	1,201	1,297	1,047	1,490	0,176	2,093	1,836	1,722	2,294	0,807	1,413	0,008	4,432	1,810	0,481	2,910	4,907	1,480
%	>50%	>50%	>70%	>70%	>60%	>70%	NS	>80%	>80%	>80%	>90%	>50%	>70%	NS	>98%	>80%	NS	>95/	>99%	>70%
30-40/50-60																				
tt	0,604	0,386	0,230	0,443	0,723	0,172	0,322	0,311	0,202	0,138	0,664	0,131	0,303	0,338	0,369	0,714	0,208	0,030	0,071	0,234
tinv-2	0,610	1,100	1,704	0,949	0,408	2,085	1,304	1,343	1,871	2,404	0,504	2,479	1,373	1,251	1,151	0,421	1,836	5,670	3,539	1,684
%	NS	>60%	>70%	>50%	NS	>80%	>60%	>60%	>70%	>80%	NS	>80%	>60%	>60%	>60%	NS	>70%	>95%	>90%	>70%
0-10/50-60																				
tt	0,948	0,677	0,241	0,330	0,539	0,013	0,984	0,830	0,167	0,067	0,189	0,186	0,066	0,146	0,036	0,025	0,654	0,579	0,225	0,217
tinv-2	0,074	0,482	1,647	1,278	0,735	8,746	0,023	0,244	2,130	3,669	1,960	1,979	3,688	2,320	5,145	6,179	0,521	0,657	1,735	1,782
%	NS	NS	>70%	>60%	NS	>98%	NS	NS	>80%	>90%	>80%	>80%	>90%	>80%	>95%	>95%	NS	NS	>70%	>70%

Appendix 11D

Table 11D-2: % Significant differences of Unbound minerals with respect to soil depths 0-10, 30-40 and 50-60 cm. NS= Not Signficant Fall 1999

Fall 1999	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
0-10		6,606		33,883		24,951		84,168		29,151		2,020		1,342		7,193		12,355		4,820
	7,442	6,940	7,795	19,942	3,759	13,203	20,781	25,787	8,825	12,652	0,800	0,670	1,397	1,982	5,801	3,238	7,428	11,175	0,968	1,119
	6,118	8,719	3,730	13,340	2,033	8,884	18,212	26,855	7,754	10,874	1,677	2,030	0,817	1,328	4,713	4,721	6,700	10,645	1,788	1,319
	12,165	5,182	15,228	27,437	4,400	12,225	18,312	12,551	11,187	17,434	2,948	0,204	2,634	0,418	7,014	2,901	7,798	5,000	3,273	1,957
	11,296	9,310	19,693	21,992	6,796	20,870	25,151	19,876	14,414	9,932	4,769	1,955	3,469	7,640	2,802	3,131	10,401	10,185	1,924	0,882
	5,828	6,013	4,469	14,908	2,365	14,254	17,475	44,846	8,559	12,939	1,131	0,468	0,812	2,716	4,016	4,830	9,766	9,037	1,932	0,712
30-40	8,575		13,452		7,556		40,400		16,305		0,031		1,861		0,911		12,137		0,749	
	0,370		2,283		0,571		1,485		5,272		0,048		0,112		1,063		1,517		0,508	
	7,274		39,869		21,616		39,971		48,460		0,144		2,420		0,536		37,408		5,685	
	19,921		10,880		8,347		55,259		10,307		0,142		4,124		1,502		10,097		2,741	
	12,492	7,911	20,740	7,110	5,018	7,657	14,587	20,328	15,607	10,146	0,096	0,044	2,735	0,729	0,331	0,543	5,317	6,536	0,959	0,378
	8,951	14,096	13,365	14,318	5,290	17,355	43,470	39,448	11,467	11,028	0,074	0,098	1,817	6,141	0,877	0,535	8,344	11,310	1,002	0,848
	10,544	9,100	8,883	6,567	2,202	7,438	17,635	21,379	7,777	13,307	0,059	0,007	2,448	1,597	0,483	0,645	5,316	9,616	1,119	0,446
50-60	9,646		6,801		4,212		30,704		10,476		0,153		1,066		0,694		8,672		1,148	
	4,595		14,655		7,402		17,780		19,753		0,081		1,212		0,766		12,759		1,125	
	9,386	12,885	15,437	16,287	7,514	10,993	10,921	15,939	12,264	10,557	0,072	0,088	1,022	1,593	0,389	0,838	6,558	7,545	6,816	1,538
	15,534	1,047	17,005	41,866	11,795	8,850	23,759	6,223	13,023	10,654	0,395	0,039	3,900	1,216	0,880	0,733	10,493	3,197	1,635	1,357
	5,595	3,756	16,129	3,005	9,756	2,548	15,798	7,310	15,242	7,041	0,001	0,120	1,718	0,523	0,561	2,021	7,388	4,476	1,354	1,120
	7,242	5,971	10,295	5,853	3,892	7,115	33,587	14,555	11,765	9,888	0,045	0,067	1,495	1,547	0,697	0,699	6,692	4,443	1,575	0,321
0-10/30-40																				
tt	0,319	0,031	0,248	0,098	0,265	0,036	0,126	0,929	0,337	0,544	0,042	0,255	0,343	0,298	0,008	0,034	0,489	0,060	0,803	0,323
tinv-2	1,315	5,571	1,614	2,947	1,535	5,102	2,546	0,101	1,252	0,724	4,727	1,581	1,233	1,395	11,293	5,311	0,841	3,899	0,285	1,302
%	>60%	>95%	>70%	>90%	>70%	>95%	>70%	NS	>60%	NS	>95%	>70%	>60%	>70%	>99%	>95%	>50%	>90%	NS	>60%
30-40/50-60																				
tt	0,666	0,083	0,601	0,641	0,937	0,458	0,597	0,143	0,630	0,245	0,633	0,307	0,441	0,469	0,605	0,334	0,607	0,037	0,818	0,365
tinv-3	0,477	2,566	0,583	0,517	0,085	0,849	0,590	1,973	0,535	1,441	0,530	1,229	0,886	0,826	0,577	1,149	0,572	3,598	0,251	1,065
%	NS	>90%	NS	NS	NS	>50%	NS	>80%	NS	>70%	NS	>60%	>50%	>50%	NS	>70%	NS	>95%	NS	>60%
0-10/50-60																				
tt	0,958	0,570	0,153	0,737	0,015	0,220	0,939	0,065	0,075	0,092	0,041	0,102	0,936	0,394	0,003	0,029	0,837	0,021	0,676	0,576
tinv-4	0,055	0,617	1,762	0,359	4,115	1,454	0,082	2,530	2,396	2,210	2,963	2,112	0,085	0,955	6,254	3,320	0,219	3,686	0,451	0,608
%	NS	NS	>80%	NS	>98%	>70%	NS	>90%	>90%	>90%	>95%	>80%	NS	>50%	>99%	>95%	NS	>90%	NS	NS

Table 11D-3: % Significant differences of Unbound minerals with respect to soil depths 0-10, 30-40 and 50-60 cm. NS= Not Signficant Spring 2000

Spring 2000	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
0-10	8,617	8,226	7,802	27,601	3,935	18,907	29,400	32,819	9,101	17,463	0,262	0,480	3,170	2,531	3,747	4,392	8,048	8,129	0,725	1,396
	7,516	4,067	3,031	30,504	1,718	13,415	32,490	23,213	14,560	17,124	0,781	0,553	0,555	3,367	8,688	4,492	6,942	8,787	0,368	1,577
	3,353	6,853	7,654	15,154	4,259	11,717	26,261	31,470	12,438	16,340	0,099	0,569	1,447	2,376	12,369	3,906	8,403	15,542	1,218	0,875
	9,456	5,981	7,788	39,530	3,346	14,775	20,200	23,912	11,428	26,040	1,386	0,321	2,368	0,990	3,480	5,039	6,683	16,080	2,129	1,307
	7,865	3,953	14,846	14,744	5,706	10,963	13,258	9,277	12,144	10,263	5,814	2,635	0,707	2,263	6,687	2,193	7,306	5,418	1,627	0,799
	8,624	4,491	36,557	23,938	11,681	14,179	26,993	15,711	29,763	13,191	2,326	1,067	7,451	3,038	2,370	1,823	30,665	13,894	1,804	0,634
30-40	6,919	7,094	2,366	3,369	1,917	8,956	30,157	20,390	11,149	12,768	0,009	0,076	2,049	1,118	0,309	5,810	7,593	9,032	0,417	0,494
	2,445	9,619	0,689	2,272	0,530	4,544	32,742	26,564	6,841	10,930	0,254	0,024	0,228	0,667	3,245	0,515	4,606	8,872	0,521	0,531
	8,136	8,138	6,537	3,106	3,960	8,054	17,233	29,701	11,248	13,964	0,031	0,018	1,532	1,164	0,433	0,958	5,039	11,741	0,521	0,429
	4,659	8,612	5,382	10,174	9,705	13,486	25,527	15,733	13,241	10,235	0,039	0,073	1,493	4,126	0,350	1,083	6,719	6,702	0,418	0,459
	3,185	2,014	1,214	1,337	1,646	4,684	49,007	40,483	8,296	9,196	0,028	0,010	0,535	0,665	0,213	0,220	6,719	6,375	0,248	0,111
	4,532	5,474	16,277	13,565	7,851	9,991	13,316	12,697	18,834	19,421	0,047	0,099	2,979	0,972	0,439	0,392	16,712	17,107	0,780	0,428
50-60		6,321		3,261		4,763		19,069		9,487		0,015		0,682		0,561		7,441		0,447
	8,451	8,425	11,962	1,284	5,668	3,407	59,385	32,568	16,035	8,268	0,064	0,007	2,736	0,566	0,626	0,414	13,342	8,780	1,249	0,474
	9,668	0,928	6,668	2,124	2,983	2,617	27,082	14,430	11,678	8,592	0,064	0,043	0,878	0,349	0,671	0,267	8,298	1,606	3,561	0,540
	9,046	6,440	4,948	4,591	4,926	6,467	37,847	32,095	11,386	9,318	0,005	0,006	3,944	1,891	0,353	0,483	9,323	8,887	1,037	0,766
	3,767	1,120	4,053	0,930	3,032	1,741	34,141	39,331	9,769	7,439	0,013	0,005	1,049	0,407	0,600	0,276	6,372	2,677	0,808	0,248
	5,528	5,487	2,090	13,019	1,722	7,032	17,407	12,799	7,373	11,781	0,029	0,038	1,112	1,267	0,475	0,746	6,049	6,640	1,070	0,428
0-10/30-40																				
tt	0,157	0,314	0,062	0,003	0,614	0,008	0,668	0,819	0,183	0,234	0,110	0,057	0,157	0,303	0,015	0,049	0,173	0,504	0,032	0,003
tinv-5	1,664	1,118	2,389	5,571	0,538	4,240	0,455	0,241	1,545	1,352	1,941	2,460	1,663	1,147	3,666	2,594	1,589	0,719	2,944	5,387
%	>80%	>60%	>90%	>99%	NS	>99%	NS	NS	>80%	>70%	>80%	>90%	>80%	>60%	>98%	>95%	>80%	NS	>95%	>99%
30-40/50-60																				
tt	0,064	0,147	0,986	0,157	0,628	0,020	0,322	0,826	0,900	0,042	0,304	0,222	0,529	0,231	0,525	0,377	0,834	0,159	0,106	0,187
tinv-4	2,544	1,793	0,018	1,741	0,523	3,759	1,130	0,235	0,134	2,952	1,178	1,443	0,688	1,413	0,696	0,992	0,224	1,728	2,081	1,590
%	>90%	>80%	NS	>80%	NS	>98%	>60%	NS	NS	>95%	>60%	>70%	NS	>70%	NS	>50%	NS	>80%	>80%	>80%
0-10/50-60																				
tt	0,971	0,754	0,334	0,014	0,518	0,000	0,170	0,515	0,338	0,050	0,113	0,075	0,731	0,074	0,025	0,010	0,577	0,058	0,868	0,023
tinv-4	0,039	0,336	1,098	4,175	0,708	18,068	1,670	0,713	1,086	2,781	2,025	2,393	0,369	2,399	3,516	4,591	0,607	2,628	0,177	3,568
%	NS	NS	>60%	>98%	NS	>100%	>80%	NS	>60%	>90%	>80%	>90%	NS	>95%	>98%	>95%	NS	>90%	NS	>95%

Appendix 11D

Table 11D-4: % Significant differences of Unbound minerals with respect to soil depths 0-10, 30-40 and 50-60 cm. NS= Not Signficant   Fall 2000

Fall 2000	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
0-10	1,581	3,645	52,075	20,332	18,264	10,324	13,587	14,583	17,410	13,344	0,419	1,091	3,717	1,317	3,329	2,150	11,225	6,637	0,697	1,000
	5,458	4,622	26,333	30,482	11,407	13,964	13,288	17,424	13,265	14,124	1,516	0,572	3,354	1,750	1,794	2,232	8,406	7,913	0,584	0,859
	7,508	4,079	17,562	61,179	6,248	20,296	19,475	46,610	13,498	35,463	4,012	0,548	1,845	10,585	3,539	14,399	14,560	27,995	1,201	1,366
	11,267	10,850	21,013	26,536	8,717	15,913	82,026	53,277	22,383	23,565	2,308	0,658	3,343	5,470	8,785	7,095	18,850	19,773	1,401	1,432
	8,053	9,395	13,378	25,224	4,335	11,352	13,810	13,685	11,271	15,004	1,389	2,502	1,023	3,897	1,557	1,654	4,854	9,560	3,969	1,398
	4,065	7,211	17,569	24,123	7,624	10,614	26,196	32,761	20,341	20,043	0,238	0,481	0,804	3,042	10,569	2,406	12,994	14,660	1,043	1,034
	2,434	7,888	27,097	38,024	10,811	20,570	45,414	58,371	27,857	31,262	0,122	1,054	1,084	3,268	5,572	7,394	14,767	22,999	1,493	1,503
	8,728	6,667	31,167	24,802	16,373	9,540	78,514	27,210	32,892	28,622	0,326	0,771	5,845	3,388	12,765	5,149	25,013	8,433	1,311	1,171
30-40	0,264	7,129	98,882	7,354	45,043	9,857	62,184	33,363	27,102	18,131	0,032	0,014	13,296	0,813	12,165	0,349	25,932	16,257	1,145	0,526
	10,837	4,032	13,116	1,687	7,253	2,994	38,890	27,069	24,671	10,269	0,014	0,022	1,753	0,394	0,463	0,420	18,693	9,669	1,030	0,181
	3,717	2,296	2,312	4,013	2,012	4,199	42,459	21,789	9,811	10,977	0,032	0,017	0,757	0,550	0,227	0,497	7,423	4,835	0,575	0,184
	9,609	14,654	21,047	15,133	8,491	12,613	26,469	42,011	19,622	21,792	0,086	0,035	0,947	1,728	0,789	0,762	14,521	18,437	0,753	0,566
	9,187	16,707	3,397	14,768	1,907	13,729	30,508	25,243	11,803	16,134	0,021	0,050	2,498	2,708	1,516	0,895	11,603	10,160	1,059	0,544
	2,676	2,370	11,451	8,661	4,611	6,843	34,875	14,488	19,948	9,970	0,404	0,021	0,222	3,175	0,266	0,598	7,152	6,650	0,499	0,194
	13,884	7,065	26,819	8,599	12,995	6,169	68,444	25,611	23,342	17,803	0,013	0,037	2,898	1,140	1,008	0,792	23,642	10,714	0,849	0,265
50-60	10,174	2,573	6,790	3,090	3,447	5,285	51,170	30,042	16,827	9,010	0,385	0,003	1,165	0,400	5,928	0,562	20,128	6,049	0,909	0,319
	5,314	3,978	9,277	4,183	6,854	6,637	34,341	44,651	25,081	13,054	0,011	0,000	1,024	0,493	0,386	0,380	16,917	12,420	1,429	0,536
	3,294	8,936	3,424	3,863	2,180	10,423	36,982	33,522	15,612	14,035	0,013	0,014	0,415	0,601	0,376	0,605	6,906	13,972	0,815	0,365
	0,866	15,011	3,598	9,455	2,215	10,976	27,166	39,101	9,569	17,444	-0,011	0,059	0,894	2,673	0,184	1,060	1,963	13,713	1,075	0,730
	14,627	11,645	6,714	7,849	2,741	10,262	46,036	48,257	13,025	17,423	0,071	0,026	1,239	2,842	2,360	1,477	12,902	16,661	0,653	0,473
	2,649	6,907	3,519	5,012	1,796	5,013	41,465	29,016	10,624	12,635	0,015	0,018	1,095	2,411	0,761	0,661	7,655	12,163	0,681	0,625
	15,191	6,445	10,134	8,284	6,470	5,169	61,408	31,070	12,803	9,607	0,093	0,011	1,815	0,797	0,911	0,491	14,829	8,994	0,908	0,332
0-10/30-40																				
tt	0,847	0,835	0,795	0,009	0,674	0,068	0,744	0,410	0,867	0,096	0,053	0,015	0,676	0,069	0,199	0,025	0,731	0,308	0,164	0,001
tinv-6	0,202	0,218	0,272	3,756	0,442	2,224	0,341	0,886	0,174	1,973	2,399	3,393	0,440	2,212	1,443	2,977	0,361	1,113	1,584	6,282
%	NS	NS	NS	>98%	NS	>90%	NS	>50%	NS	>90%	>90%	>95%	NS	>90%	>80%	>95%	NS	>60%	>80%	>100%
30-40/50-60																				
tt	0,911	0,917	0,179	0,085	0,206	0,807	0,835	0,048	0,123	0,438	0,967	0,214	0,260	0,847	0,426	0,254	0,093	0,705	0,503	0,173
tinv-6	0,117	0,109	1,522	2,057	1,420	0,256	0,217	2,471	1,791	0,830	0,043	1,388	1,243	0,202	0,854	1,262	1,994	0,397	0,712	1,548
%	NS	NS	>80%	>90%	>70%	NS	NS	>95%	>80%	>50%	NS	>70%	>70%	NS	>50%	>70%	>70%	NS	NS	>80%
0-10/50-60																				
tt	0,812	0,578	0,000	0,003	0,008	0,023	0,794	0,907	0,245	0,025	0,048	0,013	0,075	0,060	0,053	0,031	0,434	0,201	0,162	0,000
tinv-6	0,249	0,587	6,872	4,833	3,936	3,043	0,274	0,122	1,289	2,984	2,478	3,502	2,156	2,307	2,401	2,809	0,839	1,435	1,595	10,747
%	NS	NS	100%	>99%	>99%	>95%	NS	NS	>70%	>95%	>95%	>98%	>90%	>90%	>90%	>95%	>50%	>70%	>80%	100%

Appendix 11D

Table 11D-5: % Significant differences of Unbound minerals with respect to soil depths 0-10, 30-40 and 50-60 cm. NS= Not Signficant

	Al	Al	Ca	Ca	Mg	Mg	K	K	Na	Na	Fe	Fe	Mn	Mn	P	P	S	S	Zn	Zn
	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K	N	K
Spring 1999																				
0-10/30-40	>50%	>50%	>70%	>70%	>60%	>70%	NS	>80%	>80%	>80%	>90%	>50%	>70%	NS	>98%	>80%	NS	>95%	>99%	>70%
30-40/50-60	NS	>60%	>70%	>50%	NS	>80%	>60%	>60%	>70%	>80%	NS	>80%	>60%	>60%	>60%	NS	>70%	>95%	>90%	>70%
0-10/50-60	NS	NS	>70%	>60%	NS	>98%	NS	NS	>80%	>90%	>80%	>80%	>90%	>80%	>95%	>95%	NS	NS	>70%	>70%
Fall 1999																				
0-10/30-40	>60%	>95%	>70%	>90%	>70%	>95%	>70%	NS	>60%	NS	>95%	>70%	>60%	>70%	>99%	>95%	>50%	>90%	NS	>60%
30-40/50-60	NS	>90%	NS	NS	NS	>50%	NS	>80%	NS	>70%	NS	>60%	>50%	>50%	NS	>70%	NS	>95%	NS	>60%
0-10/50-60	NS	NS	>80%	NS	>98%	>70%	NS	>90%	>90%	>90%	>95%	>80%	NS	>50%	>99%	>95%	NS	>90%	NS	NS
Spring 2000																				
0-10/30-40	>80%	>60%	>90%	>99%	NS	>99%	NS	NS	>80%	>70%	>80%	>90%	>80%	>60%	>98%	>95%	>80%	NS	>95%	>99%
30-40/50-60	>90%	>80%	NS	>80%	NS	>98%	>60%	NS	NS	>95%	>60%	>70%	NS	>70%	NS	>50%	NS	>80%	>80%	>80%
0-10/50-60	NS	NS	>60%	>98%	NS	>100%	>80%	NS	>60%	>90%	>80%	>90%	NS	>95%	>98%	>95%	NS	>90%	NS	>95%
Fall 2000																				
0-10/30-40	NS	NS	NS	>98%	NS	>90%	NS	>50%	NS	>90%	>90%	>95%	NS	>90%	>80%	>95%	NS	>60%	>80%	>100%
30-40/50-60	NS	NS	>80%	>90%	>70%	NS	NS	>95%	>80%	>50%	NS	>70%	>70%	NS	>50%	>70%	>70%	NS	NS	>80%
0-10/50-60	NS	NS	100%	>99%	>99%	>95%	NS	NS	>70%	>95%	>95%	>98%	>90%	>90%	>90%	>95%	>50%	>70%	>80%	100%

Table 11E- 1: Average ion content in ppm of fine mycorrhizal oak roots from unlimed soil.

N 0-10	Bound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	4580	4125	1075	1457	211	4177	509	805	1143	75
Fall 1999	6235	2675	665	1162	162	3698	300	792	1089	105
Spring 2000	6425	3277	828	1429	289	3528	496	975	1373	115
Fall 2000	9360	5173	1244	2143	357	5167	480	969	1643	148
N 30-40	Bound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	10057	5457	1065	1403	215	1123	566	645	817	244
Fall 1999	16027	3805	859	1743	278	2255	423	585	932	158
Spring 2000	16477	2236	708	1832	221	1430	499	625	802	122
Fall 2000	18593	3026	748	1891	290	2492	402	624	848	144
N 50-60	Bound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	13347	5052	868	1247	234	1294	395	563	971	187
Fall 1999	12744	4064	1045	1634	265	1906	425	533	725	158
Spring 2000	16157	1239	633	2223	200	1843	395	572	748	104
Fall 2000	19000	2719	818	2501	316	1871	282	628	900	114

N 0-10	Unbound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	7.873	13.391	6.970	27.182	12.030	5.883	2.834	7.754	7.951	1.365
Fall 1999	8.570	10.183	3.871	19.986	10.148	2.265	1.826	4.869	8.419	1.977
Spring 2000	7.519	12.946	5.107	24.767	14.906	1.778	2.617	6.223	11.341	1.312
Fall 2000	6.137	25.774	10.472	36.539	19.865	1.291	2.627	5.989	13.834	1.463
N 30-40	Unbound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	7.577	11.219	6.160	25.681	12.174	0.071	1.901	1.752	6.894	0.640
Fall 1999	9.733	15.639	7.228	30.401	16.456	0.085	2.217	0.815	11.448	1.823
Spring 2000	4.979	5.411	4.268	27.997	11.602	0.068	1.469	0.832	7.898	0.484
Fall 2000	7.168	25.289	11.759	43.404	19.471	0.086	3.196	2.345	15.567	0.844
N 50-60	Unbound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	7.968	13.786	5.856	29.258	14.516	0.050	1.115	0.502	9.762	1.446
Fall 1999	8.666	13.387	7.429	22.092	13.754	0.124	1.735	0.664	8.760	2.275
Spring 2000	7.292	5.944	3.566	35.173	11.248	0.035	1.944	0.545	8.677	1.545
Fall 2000	7.445	6.208	3.672	42.653	14.791	0.082	1.093	1.558	1.614	0.925

Analysis provided by UKS Merzalben: LUFA Speyer

Table 11E-2: Average ion content in ppm of fine mycorrhizal oak roots from limed soil.

K 0-10	Bound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	4602	9723	2433	1078	229	4187	549	647	1181	260
Fall 1999	6284	5304	2170	2176	248	4436	622	679	1244	120
Spring 2000	9878	6413	1900	1880	289	5705	623	825	1160	204
Fall 2000	12256	5727	1727	2699	426	7356	660	940	1353	146
K 30-40	Bound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	13914	8174	1902	1507	423	1272	450	785	1177	380
Fall 1999	13848	4553	1622	1694	195	2848	475	541	725	158
Spring 2000	18398	2282	1442	1605	205	1938	506	576	814	104
Fall 2000	18270	2963	1214	1984	316	2880	272	551	853	128
K 50-60	Bound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	12155	6010	1481	1565	210	1934	481	693	845	225
Fall 1999	12640	3295	1478	1613	177	2930	251	436	644	144
Spring 2000	17342	1935	1042	2288	207	1885	369	534	723	205
Fall 2000	17503	2986	1400	2617	333	3093	279	542	886	125

K 0-10	Unbound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	3.684	39.202	23.653	18.987	18.975	1.553	3.158	5.763	10.862	2.325
Fall 1999	7.128	21.917	35.681	35.681	15.497	1.225	2.510	4.336	9.733	1.801
Spring 2000	5.595	25.245	22.734	22.734	16.737	0.938	2.428	3.641	11.308	1.098
Fall 2000	6.795	31.338	32.990	32.990	22.678	0.960	4.090	5.310	14.746	1.220
K 30-40	Unbound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	13.538	34.609	31.821	53.802	37.504	0.093	2.006	0.690	27.206	1.400
Fall 1999	10.369	9.331	10.817	27.052	11.494	0.495	2.823	0.574	9.154	0.558
Spring 2000	6.825	5.637	8.286	24.262	12.752	0.050	1.452	1.496	9.972	0.409
Fall 2000	7.750	8.602	8.057	27.082	15.011	0.028	1.501	0.616	10.960	0.352
K 50-60	Unbound									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	5.496	20.696	9.860	19.776	12.542	0.820	1.452	0.843	8.498	0.818
Fall 1999	5.915	16.753	7.377	11.007	9.535	0.787	1.220	1.073	4.915	1.084
Spring 2000	4.787	4.201	4.338	25.049	9.148	0.019	0.861	0.458	6.005	0.484
Fall 2000	7.928	5.962	7.681	36.523	12.315	0.019	1.460	0.748	1.996	0.483

Analysis provided by UKS Merzalben: LUFA Speyer

Table 11E-3: Ratios of bound (B) to unbound (U) minerals in unlimed (N) and limed (K) probes.

N 0-10	Ratio B:U									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	582	308	154	54	18	710	180	104	144	55
Fall 1999	728	263	172	58	16	1633	164	163	129	53
Spring 2000	855	253	162	58	19	1984	190	157	121	88
Fall 2000	1525	201	119	59	18	4002	183	162	119	101
N 30-40	**Ratio B:U**									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	1327	486	173	55	18	15862	298	368	119	381
Fall 1999	1647	243	119	57	17	26623	191	718	81	87
Spring 2000	3309	413	166	65	19	21029	340	752	102	252
Fall 2000	2594	120	64	44	15	29044	126	266	54	171
N 50-60	**Ratio B:U**									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	1675	366	148	43	16	25880	354	1122	99	129
Fall 1999	1471	304	141	74	19	15334	245	802	83	69
Spring 2000	2216	208	177	63	18	52808	203	1049	86	67
Fall 2000	2552	438	223	59	21	22734	258	403	558	123

K 0-10	Ratio B:U									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	1249	248	103	57	12	2696	174	112	109	112
Fall 1999	882	242	61	61	16	3622	248	157	128	67
Spring 2000	1765	254	84	83	17	6085	257	227	103	186
Fall 2000	1804	183	52	82	19	7665	161	177	92	120
K 30-40	**Ratio B:U**									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	1028	236	60	28	11	13619	224	1138	43	271
Fall 1999	1336	488	150	63	17	5754	168	942	79	283
Spring 2000	2696	405	174	66	16	38838	348	385	82	254
Fall 2000	2357	344	151	73	21	103226	181	894	78	364
K 50-60	**Ratio B:U**									
	Al	Ca	Mg	K	Na	Fe	Mn	P	S	Zn
Spring 1999	2212	290	150	79	17	2359	331	822	99	275
Fall 1999	2137	197	200	147	19	3723	206	407	131	133
Spring 2000	3623	461	240	91	23	99211	429	1166	120	424
Fall 2000	2208	501	182	72	27	165401	191	725	444	259

Appendix 11F
Statistical analysis of B:U Ratios

Table 11F-1: Bound and Unbound Al, Ca, and Mg at various depths and seasons

	Unlimed Bound	Unlimed Unbound	Unlimed Ratio B:U	Limed Bound	Limed Unbound	Limed Ratio B:U	t-test	tinv-3	% SD
	Al N 0-10			Al K 0-10					
Spring 1999	4580	7.873	582	4602	3.684	1249	0.064	2.880	>90%
Fall 1999	6235	8.570	728	6284	7.128	882			
Spring 2000	6425	7.519	855	9878	5.595	1765			
Fall 2000	9360	6.137	1525	12256	6.795	1804			
	Al N 30-40			Al K 30-40					
Spring 1999	10057	7.577	1327	13914	13.538	1028	0.023	4.329	>95%
Fall 1999	16027	9.733	1647	13848	10.369	1336			
Spring 2000	16477	4.979	3309	18398	6.825	2696			
Fall 2000	18593	7.168	2594	18270	7.750	2357			
	Al N 50-60			Al K 50-60					
Spring 1999	13347	7.968	1675	12155	5.496	2212	0.213	1.578	>70%
Fall 1999	12744	8.666	1471	12640	5.915	2137			
Spring 2000	16157	7.292	2216	17342	4.787	3623			
Fall 2000	19000	7.445	2552	17503	7.928	2208			

	Unlimed Bound	Unlimed Unbound	Unlimed Ratio B:U	Limed Bound	Limed Unbound	Limed Ratio B:U	t-test	tinv-3	% SD
	Ca N 0-10			Ca K 0-10					
Spring 1999	4125	13.391	308	9723	39.202	248	0.1521	1.910	>80%
Fall 1999	2675	10.183	263	5304	21.917	242			
Spring 2000	3277	12.946	253	6413	25.245	254			
Fall 2000	5173	25.774	201	5727	31.338	183			
	Ca N 30-40			Ca K 30-40					
Spring 1999	5457	11.219	486	8174	34.609	236	0.681	0.454	NS
Fall 1999	3805	15.639	243	4553	9.331	488			
Spring 2000	2236	5.411	413	2282	5.637	405			
Fall 2000	3026	25.289	120	2963	8.602	344			
	Ca N 50-60			Ca K 50-60					
Spring 1999	5052	13.786	366	6010	20.696	290	0.714	0.403	NS
Fall 1999	4064	13.387	304	3295	16.753	197			
Spring 2000	1239	5.944	208	1935	4.201	461			
Fall 2000	2719	6.208	438	2986	5.962	501			

	Unlimed Bound	Unlimed Unbound	Unlimed Ratio B:U	Limed Bound	Limed Unbound	Limed Ratio B:U	t-test	tinv-3	% SD
	Mg N 0-10			Mg K 0-10					
Spring 1999	1075	6.970	154	2433	23.653	103	0.009	6.064	>99%
Fall 1999	665	3.871	172	2170	35.681	61			
Spring 2000	828	5.107	162	1900	22.734	84			
Fall 2000	1244	10.472	119	1727	32.990	52			
	Mg N 30-40			Mg K 30-40					
Spring 1999	1065	6.160	173	1902	31.821	60	0.9426	0.078	NS
Fall 1999	859	7.228	119	1622	10.817	150			
Spring 2000	708	4.268	166	1442	8.286	174			
Fall 2000	748	11.759	64	1214	8.057	151			
	Mg N 50-60			Mg K 50-60					
Spring 1999	868	5.856	148	1481	9.860	150	0.460	0.845	>50%
Fall 1999	1045	7.429	141	1478	7.377	200			
Spring 2000	633	3.566	177	1042	4.338	240			
Fall 2000	818	3.672	223	1400	7.681	182			

t-test = student t-test, tinv = inverse of t-test, %SD = Signficant Difference, NS = No Significant Difference

Table 11F-2: Bound and Unbound K, Na, and Fe at various depths and seasons.

	Unlimed			Limed					
	Bound	Unbound	Ratio B:U	Bound	Unbound	Ratio B:U	t-test	tinv-3	% SD
	K N 0-10			K K 0-10					
Spring 1999	*1457*	*27.182*	*54*	*1078*	*18.987*	*57*	*0.1128*	*2.223*	*>80%*
Fall 1999	*1162*	*19.986*	*58*	*2176*	*35.681*	*61*			
Spring 2000	*1429*	*24.767*	*58*	*1880*	*22.734*	*83*			
Fall 2000	*2143*	*36.539*	*59*	*2699*	*32.990*	*82*			
	K N 30-40			K K 30-40					
Spring 1999	*1403*	*25.681*	*55*	*1507*	*53.802*	*28*	*0.8567*	*0.197*	*NS*
Fall 1999	1743	30.401	*57*	1694	27.052	*63*			
Spring 2000	*1832*	*27.997*	*65*	*1605*	*24.262*	*66*			
Fall 2000	*1891*	*43.404*	*44*	*1984*	*27.082*	*73*			
	K N 50-60			K K 50-60					
Spring 1999	*1247*	*29.258*	*43*	*1565*	*19.776*	*79*	*0.059*	*2.971*	*>90%*
Fall 1999	*1634*	*22.092*	*74*	*1613*	*11.007*	*147*			
Spring 2000	*2223*	*35.173*	*63*	*2288*	*25.049*	*91*			
Fall 2000	*2501*	*42.653*	*59*	*2617*	*36.523*	*72*			
	Bound	Unbound	Ratio B:U	Bound	Unbound	Ratio B:U	t-test	tinv-3	% SD
	Na N 0-10			Na K 0-10					
Spring 1999	*211*	*12.030*	*18*	*229*	*18.975*	*12*	*0.3169*	*1.198*	*>60%*
Fall 1999	*162*	*10.148*	*16*	*248*	*15.497*	*16*			
Spring 2000	*289*	*14.906*	*19*	*289*	*16.737*	*17*			
Fall 2000	*357*	*19.865*	*18*	*426*	*22.678*	*19*			
	Na N 30-40			Na K 30-40					
Spring 1999	*215*	*12.174*	*18*	*423*	*37.504*	*11*	*0.7883*	*0.293*	*NS*
Fall 1999	278	16.456	*17*	195	11.494	*17*			
Spring 2000	*221*	*11.602*	*19*	*205*	*12.752*	*16*			
Fall 2000	*290*	*19.471*	*15*	*316*	*15.011*	*21*			
	Na N 50-60			Na K 50-60					
Spring 1999	*234*	*14.516*	*16*	*210*	*12.542*	*17*	*0.1936*	*1.670*	*>80%*
Fall 1999	*265*	*13.754*	*19*	*177*	*9.535*	*19*			
Spring 2000	*200*	*11.248*	*18*	*207*	*9.148*	*23*			
Fall 2000	*316*	*14.791*	*21*	*333*	*12.315*	*27*			
	Bound	Unbound	Ratio B:U	Bound	Unbound	Ratio B:U	t-test	tinv-3	% SD
	Fe N 0-10			Fe K 0-10					
Spring 1999	*4177*	*5.883*	*710*	*4187*	*1.553*	*2696*	*0.0131*	*5.297*	*>98%*
Fall 1999	*3698*	*2.265*	*1633*	*4436*	*1.225*	*3622*			
Spring 2000	*3528*	*1.778*	*1984*	*5705*	*0.938*	*6085*			
Fall 2000	*5167*	*1.291*	*4002*	*7356*	*0.960*	*7665*			
	Fe N 30-40			Fe K 30-40					
Spring 1999	*1123*	*0.071*	*15862*	*1272*	*0.093*	*13619*	*0.4639*	*0.837*	*>50%*
Fall 1999	2255	0.085	*26623*	2848	0.495	*5754*			
Spring 2000	*1430*	*0.068*	*21029*	*1938*	*0.050*	*38838*			
Fall 2000	*2492*	*0.086*	*29044*	*2880*	*0.028*	*103226*			
	Fe N 50-60			Fe K 50-60					
Spring 1999	*1294*	*0.050*	*25880*	*1934*	*0.820*	*2359*	*0.3851*	*1.014*	*>60%*
Fall 1999	*1906*	*0.124*	*15334*	*2930*	*0.787*	*3723*			
Spring 2000	*1843*	*0.035*	*52808*	*1885*	*0.019*	*99211*			
Fall 2000	*1871*	*0.082*	*22734*	*3093*	*0.019*	*165401*			

t-test = student t-test, tinv = inverse of t-test, %SD = Signficant Difference, NS = No Significant Difference

Table 11F-3: Bound and Unbound Mn, P, and S at various depths and seasons

	Unlimed Bound	Unlimed Unbound	Unlimed Ratio B:U	Limed Bound	Limed Unbound	Limed Ratio B:U	t-test	tinv-3	% SD
	Mn N 0-10			Mn K 0-10	3				
Spring 1999	509	2.834	180	549	3.158	174	0.3217	1.184	>60%
Fall 1999	300	1.826	164	622	2.510	248			
Spring 2000	496	2.617	190	623	2.428	257			
Fall 2000	480	2.627	183	660	4.090	161			
	Mn N 30-40			Mn K 30-40					
Spring 1999	566	1.901	298	450	2.006	224	0.7893	0.292	NS
Fall 1999	423	2.217	191	475	2.823	168			
Spring 2000	499	1.469	340	506	1.452	348			
Fall 2000	402	3.196	126	272	1.501	181			
	Mn N 50-60			Mn K 50-60					
Spring 1999	395	1.115	354	481	1.452	331	0.7449	0.357	NS
Fall 1999	425	1.735	245	251	1.220	206			
Spring 2000	395	1.944	203	369	0.861	429			
Fall 2000	282	1.093	258	279	1.460	191			

	Bound	Unbound	Ratio B:U	Bound	Unbound	Ratio B:U	t-test	tinv-3	% SD
	P N 0-10			P K 0-10					
Spring 1999	805	7.754	104	647	5.763	112	0.2793	1.317	>70%
Fall 1999	792	4.869	163	679	4.336	157			
Spring 2000	975	6.223	157	825	3.641	227			
Fall 2000	969	5.989	162	940	5.310	177			
	P N 30-40			P K 30-40					
Spring 1999	645	1.752	368	785	0.690	1138	0.3055	1.233	>60%
Fall 1999	585	0.815	718	541	0.574	942			
Spring 2000	625	0.832	752	576	1.496	385			
Fall 2000	624	2.345	266	551	0.616	894			
	P N 50-60			P K 50-60					
Spring 1999	563	0.502	1122	693	0.843	822	0.731	0.377	NS
Fall 1999	533	0.664	802	436	1.073	407			
Spring 2000	572	0.545	1049	534	0.458	1166			
Fall 2000	628	1.558	403	542	0.748	725			

	Bound	Unbound	Ratio B:U	Bound	Unbound	Ratio B:U	t-test	tinv-3	% SD
	S N 0-10			S K 0-10					
Spring 1999	1143	7.951	144	1181	10.862	109	0.0645	2.861	>90%
Fall 1999	1089	8.419	129	1244	9.733	128			
Spring 2000	1373	11.341	121	1160	11.308	103			
Fall 2000	1643	13.834	119	1353	14.746	92			
	S N 30-40			S K 30-40					
Spring 1999	817	6.894	119	1177	27.206	43	0.4411	0.886	>50%
Fall 1999	932	11.448	81	725	9.154	79			
Spring 2000	802	7.898	102	814	9.972	82			
Fall 2000	848	15.567	54	853	10.960	78			
	S N 50-60			S K 50-60					
Spring 1999	971	9.762	99	845	8.498	99	0.8453	0.213	NS
Fall 1999	725	8.760	83	644	4.915	131			
Spring 2000	748	8.677	86	723	6.005	120			
Fall 2000	900	1.614	558	886	1.996	444			

t-test = student t-test, tinv = inverse of t-test, %SD = Signficant Difference, NS = No Significant Difference

Table 11F-4: Bound and Unbound Zn at various depths and seasons

	Unlimed Bound	Unlimed Unbound	Unlimed Ratio B:U	Limed Bound	Limed Unbound	Limed Ratio B:U	t-test	tinv-3	% SD
	Zn N 0-10			Zn K 0-10					
Spring 1999	*75*	*1.365*	*55*	*260*	2.325	*112*	*0.0981*	*2.374*	*>90%*
Fall 1999	*105*	*1.977*	*53*	*120*	*1.801*	*67*			
Spring 2000	*115*	*1.312*	*88*	*204*	*1.098*	*186*			
Fall 2000	*148*	*1.463*	*101*	*146*	*1.220*	*120*			
	Zn N 30-40			Zn K 30-40					
Spring 1999	*244*	*0.640*	*381*	*380*	*1.400*	*271*	*0.418*	*0.937*	*>50%*
Fall 1999	158	1.823	*87*	158	0.558	*283*			
Spring 2000	122	*0.484*	*252*	*104*	*0.409*	*254*			
Fall 2000	*144*	*0.844*	*171*	*128*	*0.352*	*364*			
	Zn N 50-60			Zn K 50-60					
Spring 1999	*187*	*1.446*	*129*	*225*	*0.818*	*275*	*0.069*	*2.780*	*>90%*
Fall 1999	*158*	2.275	*69*	*144*	*1.084*	*133*			
Spring 2000	*104*	*1.545*	*67*	*205*	*0.484*	*424*			
Fall 2000	*114*	*0.925*	*123*	*125*	*0.483*	*259*			

t-test = student t-test, tinv = inverse of t-test, %SD = Signficant Difference, NS = No Significant Difference

Appendix 12: Micrographs of Individual Ectomycorrhizal Species

In this appendix, individual ectomycorrhizal species, from unlimed and limed forest zones, will be presented with demonstrative photographs and a discussion of their relative aluminum (Al) contents. The photographs include features such as characterisitic gross morphology, autofluorescence, and Morin staining reactions. The figures list the probe number which identifies the tree, forest zone, soil depth and season along with photographic data which includes the type of section (Lx = long section, Cx = cross-section), magnification (125 to 1000x), photo number code (ie- 6-3 = film 6, photo 3), fluorescent filter used (Clear = no UV filter block, CSF#1, Green = green UV filter block, CSF#2 which was used occasionally only to improve contrast), exposure time in seconds (shorter exposure time was related to intense color reactions), and duration of Morin dye reaction. In reference to the Morin treatment time, very generally, a yellow color reaction implies the presence of Al, but because there are different concentrations of the metal, a green reaction can also indicate the presence of Al, but at lower concentrations, usually found as tiny specks. The time required for a Morin-Al reaction is relevant since intense deposits of Al will react more quickly (5 minutes or less) but low content results in a much longer time for a color reaction to occur (up to 20 minutes). As a result, the treatment time is provided. In the discussion for each species, relevent information is divided into categories which are briefly described in this introduction to Appendix 12. Further information concerning microscope and filters is provided in Section E1.

Mycorrhizal species : All species names are given in italics to differentiate them in this text, even if they are not truly considered to be accepted species. If a "Genus" name is the same as that of the host tree type, this "species" has not yet been fully accredidated but just acknowledged as a morphotype. Differentiation between true and possible species is made in Section B. Alternate names for the species are provided in Appendix 2B.

Fruiting body Occurrence: Many of the ectomycorrhizal symbionts have no known fruiting structures. If fruiting bodies were found in Merzalben, their presence was noted. It must be clarified however that the search for surface fruiting was random and only done in the fall. The fruiting bodies were not traced along their hyphae back to subsurface mycorrhizae. Appendix 2 contains information concerning all the fruiting structures found including their alternate names, dendrology and habitat preferences. Above ground fruiting could not be correlated with changes in below ground mycorrhizal abundance.

Mycorrhizal Occurrence: The relative seasonal, depth and location abundance of each species in comparison to the other species found in Merzalben ia presented in detail in Appendix 8A. The probes used for fluorescence analysis are presented in appendix 7.

Mycorrhizal Morphology: The micrographs created by Agerer (1987-1998) were used as a base reference point in order to give a more discriptive name rather than a static non-descriptive number to the morphotypes found. Species identification and confirmation was done on three levels (1) by color and biochemical reactions (2) by fine morphological surface details and growth forms which will be refered to as "gross morphology" in the photographic figures and (3) by cellular patterns of the hyphae, rhizomorphs, mantle and cystidia using the sections prepared for fluorescence microscopy. In a few cases distinguishing features were noted. Photographs of most of the species are provided in the introduction to Section B. On this basis, tentative identification was assigned. It was recognized that, in this expanding field, DNA or RNA analysis may alter these definitions.

Fungal Autofluorescence: Root Autofluorescence: Fungal Aluminum: Root Aluminum: Summary: These subcategories deal with an explanation of the tabular results presented in Appendix 7. An attempt was made to draw general seasonal trends from the data but with trepidation since the natural mycorrhizal systems are truly dynamic and adaptive, and by their very nature are responsive to a myriad of microenvironmental factors in their quest for nutrition, moisture and survival. The adjacent test areas had the same altitude, annual rainfall, temperature, soil type, slope, and tree distributio, but the effects of these factors, in particular seasonal climatic changes, pH, soil desiccation and rehydration had a definite and differential impact on the mycorrhizae in the compared plots. The effects on diversity and abundance are presented in Section B. The effects on Al content are presented in Sections C, E and F, Appendix 7, and here in Appendix 12.

APPENDIX 12 : ECTOMYCORRHIZAL SPECIES MICROPHOTOGRAPHS

The fluorescent photographic standards and histochemical tests used in this study are presented in Section E. In summary, Cross- and Long- cryosections, and rhizomorph detail was achieved using a Leitz Wetzlar Ortholux 2, trinocular Fluorescence microscope (Leica Mikrosysteme Vertrieb GmbH, D-64625 Bensheim, Germany) with NPL Fluotar objective lenses and a OSRAM HBO 50 W/AC-L1, 39-45V/50W Leica Wetzlar short arc mercury vapor lamp (See Section E3) and a OSRAM 8100S 6V/5A white lamp and Leica camera DRP Nr. 677597 (Ernst Leitz GmgH, Wetzlar, Germany) and a Profisystem light meter (Profisix, Gossen, Germany). Unless otherwise stated, the autofluorescence and Morin treatments were viewed, recorded and photographed using a LRF#1, SRF#2 and CSF clear filter combinations (See Section E6) which gave the most information, fastest color reactions and best light emmission (UV-B: 280-315 nm and UV-A: 315-380 nm) for photographs and Morin reactions. For oil immersion, 70-80% Di (TCD-Methylole)-adiptic acid ester immersion oil (Leica Microsystems Wetzlar GmbH # 11513859) was used to reduce diffraction of UV light. The standard film used was 135 mm 100 / 21^0 ASA Sensia II Fujichrome color slide film. Photographs showing gross morphology of the whole mycorrhizae were made using a Leica MZ8 trinocular Stereomicrosope with Nikon camera and 135 mm 100 / 21 ^{0} ASA Sensia II Fujichrome color slide film or 135 mm Elitechrome Kodak Select Series 100 ASA color slide film.

Typical Root Autofluorescence: In oak roots the "Typical" fluorescence of all the cells is blue with the exception of the phloem which tends to be non-fluorescent. The endodermal an pericycle ring cells tend to fluoresce the most intensely.

Appendix 12-1: Amphinema byssoides

Fruiting body Occurrence: None found (Appendix 2A).

Mycorrhizal Occurrence: Rare in unlimed moist soil otherwise absent, but many were found on oak fine roots in limed soil. The mycorrhizae were rarely present in the limed soil at 0-10 cm depth in the dry spring but were more prevalent the dry fall season, declining the following spring and increasing to their greatest abundance in the wet fall 2000.. This implies good potential for recovery following desiccation stress in limed soil in a species that is normally rare to seldom present in unlimed soil (Appendix 8A- B3-1). Mycorrhizae used in the descriptions below can be found in detail in Appendix 7-1.

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 23. (Figure 12-1A).

Fungal Autofluorescence: Emanating hyphae at 0-10 cm depth appeared bluish (dry spring, limed) to faint yellow (dry fall, limed), and in unlimed probes in the wet fall they were blue (younger) to green (older). The yellow color change may imply phenol deposition as a physiological response to desiccation stress with recovery associated with a return to bluish coloration while the green tones may be a normal aging phenomenon. Further research needs to be done to confirm this. The fungal mantle at 0-10 cm soil depth was non-fluorescent (dry spring) to faintly yellow (dry fall) in limed soil, and at 50-60 cm depth (wet fall) in unlimed soil, the mantle was bluish at <1 mm (younger) to greenish at >5 mm (older zone) from the tip. Also implying physiological changes associated with seasonal dehydration and rehydration. The Hartig net and corresponding root cells were faintly bluish (dry spring) to blue (dry fall) at 0-10 cm depth in limed soil, but at 50-60 cm depth (wet fall) in unlimed soil, the Hartig net in the region of the epidermal cells was orange (<1 mm) to yellowish (>5 mm) implying a change in barrier location during recovery phase at this depth. (Appendix 7- Summary 1).

Root Autofluorescence: Xylem was blue-yellow (spring) to blue (fall) in limed probes. Phloem was primarily non-fluorescent (0-10 and 30-40 cm, limed probes) to very faintly orange (50-60 cm depth, unlimed probes). The pericycle and endodermis were faintly blue (spring) to blue (fall). The cortex was very faintly bluish (spring) to blue (fall). Other than the faint orange tinge to the phloem cell walls, the root autofluorescence was typical for fine oak roots from both the unlimed and limed soils. (Appendix 7- Summary 1).

Fungal Aluminum: Aluminum, which fluoresces yellow in the presence of Morin, was generally absent from the mature fungal mantle cells in the dry spring, but questionably present in the dry fall in limed probes (Figure 12-1B). In the wet fall, in unlimed probes, young bluish mantle cells and hyphae at 50-60 cm depth became suspiciously green in the presence of Morin, which implies possible presence of an Al-complex in conjunction with other wall-binding minerals. At 0-10 cm depth, Al was faintly (dry spring) to strongly (dry fall) present in the young emanating hyphae however, while faintly present in the dry spring, Al was present in the spring but absent in the Hartig net region in the dry fall in the limed probes. This implies the emanating hyphae and to a lesser extent, the mantle, were sequestered the Al preventing its translocation to the Hartig net in increasingly desiccated soils but in the spring an alternate mechanism was operating. Very generally, the more Al that is sequestered in the outer regions of the mycorrhiza, the less reaches the cortex and xylem and inversely, the less able the mycorrhiza is in sequestering Al, more is translocated to the inner root. But, it is essential to note that these physiological changes were correlated to seasonal microclimatic effects.

Root Aluminum: Aluminum was heavily present in the cortical and xylem cell walls in the spring of 1999 as well as variably present in the outer endodermal walls on the cortical side of the casparian band but relatively absent or less evident in the outer mantle regions at the same time in the limed probes (Figure 12-1B, C). In the very dry fall of 1999 in the limed probes, although still present in the xylem, Al was absent from the cortex while correspondingly more seemed to be present in the outer mantle and emanating hyphae. In dry soil, the hyphae of the fungal mantle of this species can effectively sequester Al, acting as a barrier to its translocation. In the wet fall in the 50-60 cm depth probes in unlimed soil, Al was very variable but still present in the cortex and sometimes absent in the xylem. It was difficult to determine if the mantle and emanating hyphae truly contained Al due to the masking influence of the greenish to yellowish autofluorescence. It seems likely however that some barrier complex was present in the autofluorescing fungal cells that effectively reduced the Al content of the cortex

Summary: Young *Amphinema byssoides* mycorrhizae were less able to stop Al translocation to the root, than older rhizomorphs and mantle cells which had more competent sequestration, especially in desiccating limed soil. The formation of Al-barriers (low sequestration) in fungal walls, seems to be associated with deposition of a green-fluorescent complex that forms upon aging and with depth in the unlimed probes. By qualitative analysis, more Al was held by the mycorrhizae and roots in limed soils than in unlimed soils. But enhanced Al-sequestration in fungal cells comes at a price, resulting in the loss of species that approach toxic concentrations. Intense Al-sequestration in limed tips in the fall of 1999 was followed by a species decline the following spring. Reappearance of the species a year following a severe stress indicates possible adaptive survival.

Excessive acidity in soil seems to be associated with lower ability to sequester toxic aluminum ions. The acidified aluminum would be then able to more freely translocate into the root. The fact that was not sequestered by the root cortical or xylem cells implies that acidity may also adversely affect their physiological responses and ability to hold the ions. Once in the mass flow of the xylem tubes the Al would then be free to flow to their end points in the leaves where they can interfere with photosynthesis by tying up phosphates or interfering with DNA and cell division resulting in toxicity and leaf loss. This scenario is somewhat supported by the observation of 25% more light penetration through the crowns of trees in the unlimed forest areas. Liming then, by enhancing Al sequestration, effectively reduces Al translocation to sensitive growing areas and reduces leaf loss...... until a severe drought occurs. Sudden release of Al accumulated strongly in limed roots over many years, by the hydration period that follows a severe drought may be the "shock factor" that causes massive leaf die off and sudden oak death.

Figure 12-1A: *Amphinema byssoides* gross morphology. A portion of a mycorrhizal system showing bent tips with a shiny (air pockets) white mantle surrounded by a cloud of very fine emanating hyphae. Probe 200K from limed soil at 30-40 cm depth in spring 2000. 250x. Photo 4-7.

Figure 12-1B: *Amphinema byssoides* mantle with Morin < 5 mm from tip. Most of the very thick mantle is Al-free (blue) , with minor Al-components (green) or has Al distinctly evident (yellow) (bottom left). The elongated cells of the Hartig net and the cortical cell seen contain minimal Al (faint green) (lower right). Probe 1000K from limed soil at 50-60 cm depth in fall 2000. Cx. 1000x. Photo 19-28, clear filter, 60 second exposure, 10 minutes after treatment.

Figure 12-1C: *Amphinema byssoides* root with Morin < 5 mm from tip. When the mantle is low in Al, the cortex is often very strong. The inner cortical cells are visible here with very thick walls, bright yellow with Al while the small endodermal barrier cells and the periderm, which form the ring at the bottom of the photo, are blue (Al-free). Probe 1000K from limed soil at 50-60 cm depth in fall 2000. This is a different root section from Figure 12-1B but from the same soil probe. Cx. 1000x. Photo 19-30, clear filter, 45 second exposure, 5 minutes after treatment.

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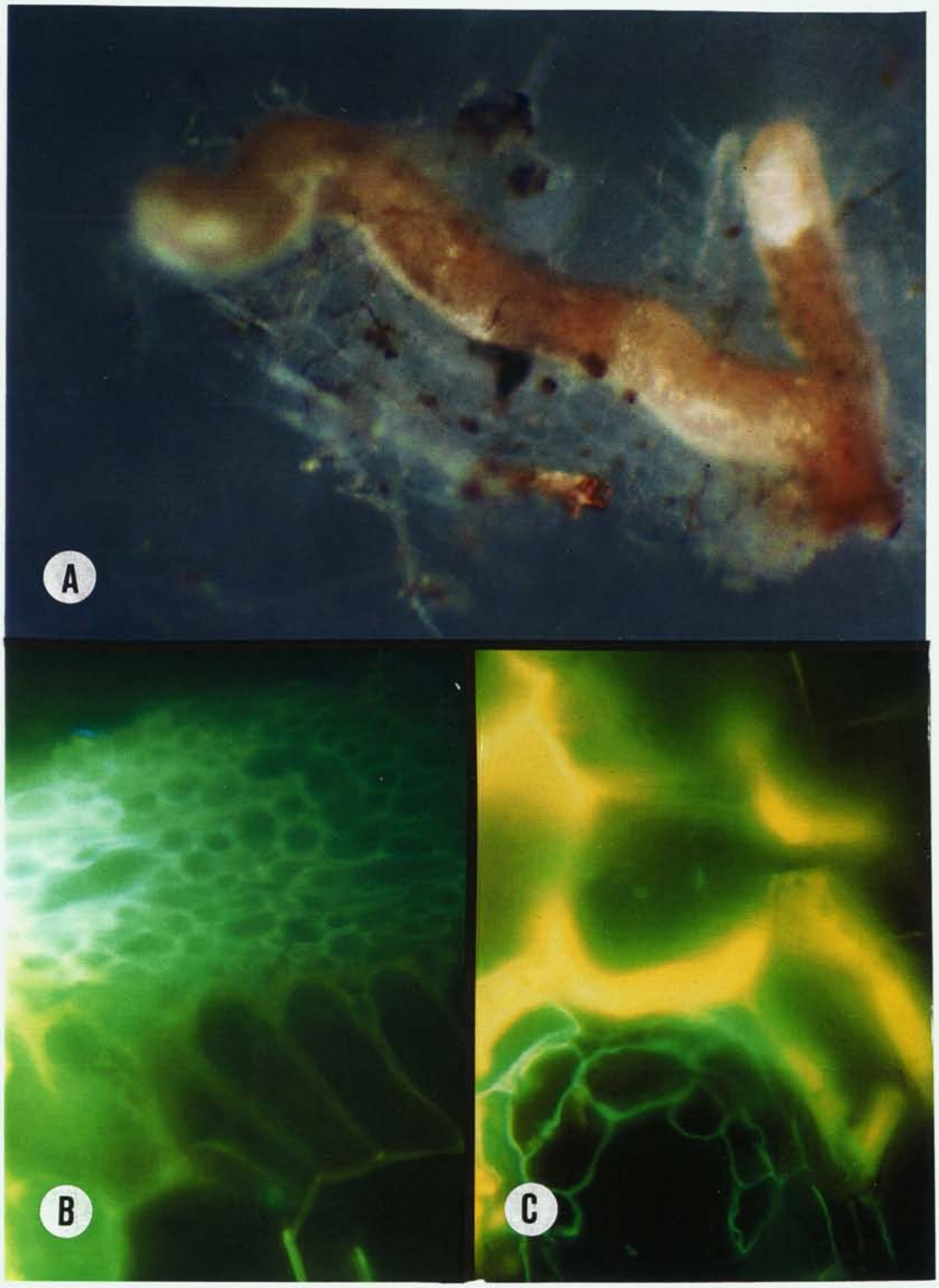


Appendix 12-2: Boletinus cavipes

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare in unlimed soils as isolated tips, randomly present, with the best representation occurring in fall 1999 & spring 2000 at 30-40 cm depth (Appendix 8A-B3-2). Fluorescence results were taken from a spring 1999 sample from 0-10 cm depth (Probe1N) (Appendix 7-2). No comparative samples from limed soil were available.

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 35. (Figure 12-2A, B, C)

Fungal Autofluorescence: Emanating hyphae and rhizomorphs were blue to faint yellow. Outer mantle cells which formed club shaped extensions, were very faint to faint blue, while the inner mantle was strong blue and Hartig net cells were faint blue to very faint yellow (<1 mm) to bluish yellow (>5 mm) at 0-10 cm depth. (Appendix 7-2). Unlimed probes only were available (Figure 12-2B, C).

Root Autofluorescence: Xylem, pericycle and endodermal cell walls were bluish while the cortical cell walls appeared blue to yellowish. Since the cortical cells are normally bluish, the yellowish coloration may be influenced by *Boletinus cavipes.*

Fungal Aluminum: Generally Al was absent from the inner mantle and Hartig net, but variably present (faint to strong yellow and occasionally green) in the emanating hyphae of the outer mantle. Some large Al specks were present in the outer (epidermal) Hartig net area >5 mm from the tip.

Root Aluminum: Cortex, xylem and outer endodermis contained Al at <1 mm, but at > 5 mm Al was absent from the xylem and endodermis though still present in the cortical walls. The Al root content was inversely related to the fungal content.

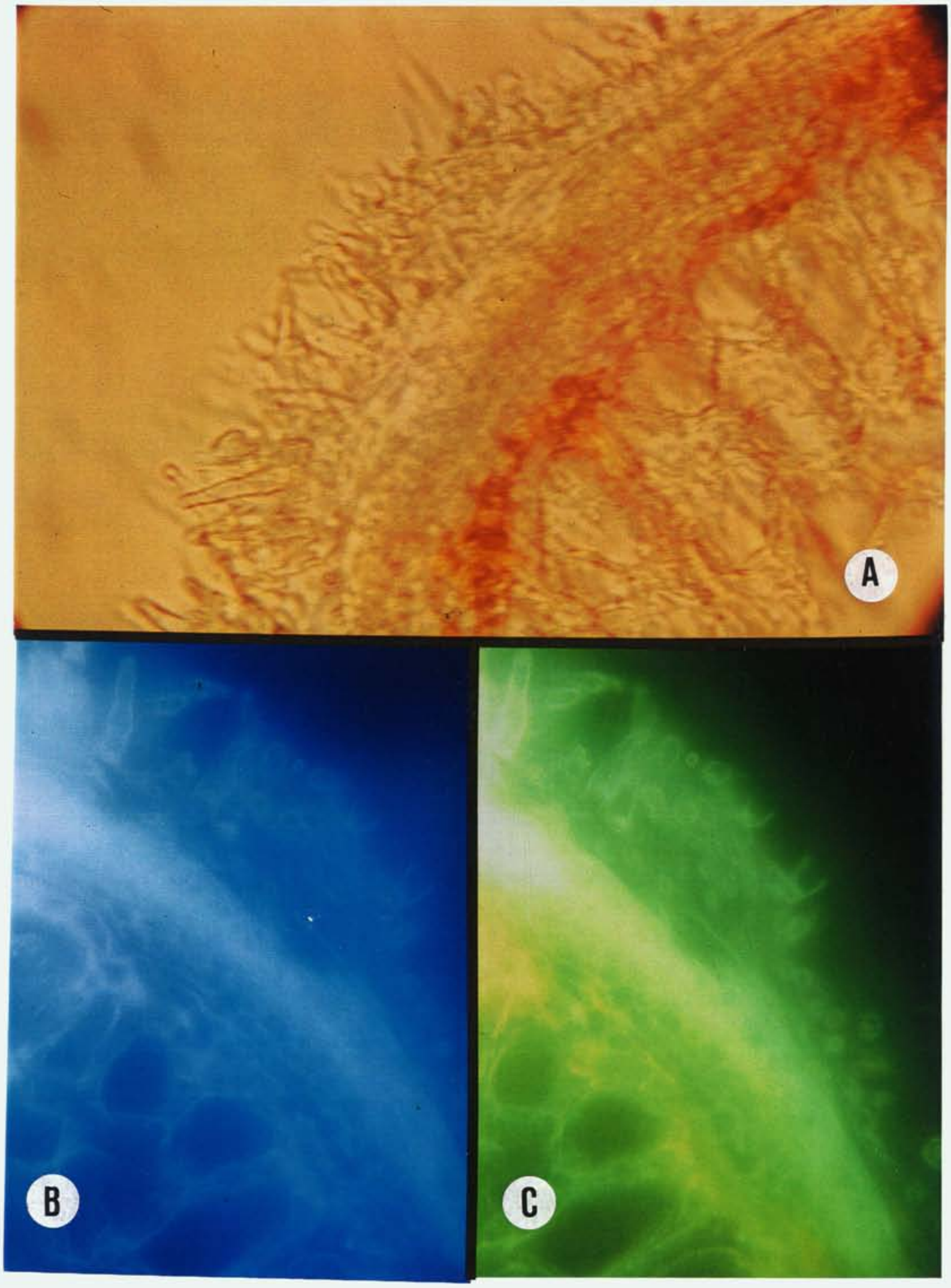
Summary: A tentative, but not definitive, correlation between the lack of Al in the mantle and its presence in the cortex could only be made, due to the small sampling size. Al cortex content was inversely related to fungal content.

Figure 12-2A: *Boletinus cavipes* gross morphology. The outer mantle (> 5 mm from tip) is covered with hyphal projections which have a club shape, very similar to traditional cystidia. Some have bulbous ends. The inner mantle is very thick implying strong growth. The Hartig net cells are present but not easily visible here due to poor contrast (See Figure 12-2B).Probe 6NA from unlimed soil at 30-40 cm depth in spring 1999. Cx. 1000x. Photo 8-3, white light, 26 second exposure.

Figure 12-2B: *Boletinus cavipes* autofluorescence > 5 mm from tip. The fungal and root cells all fluoresced blue with the brightest blue present in the inner mantle in the filter combination used for all subsequent fluorescence testing. Probe 6NA from unlimed soil at 30-40 cm depth in spring 1999. Cx. 1000x. Photo 8-4, SRF#1 (blue) + CSF#1 (clear filter), 43 second exposure.

Figure 12-2C: *Boletinus cavipes* autofluorescence > 5 mm from tip, filter change. The use of a SRF#2 (green) filter altered the autofluorescence to the green end of the spectrum when using the CSF#1 (clear) filter. The presence of conflicting green or yellow tones interfered with interpretation of Morin staining but was of significance since it was desired to avoid false positives which could only be determined by determining the underlying autofluorescence. The CSF#2 filter light was much stronger than CSF#1 and resulted in faster reactions and better photographs. A combination of SRF#1 (clear) and CSF#1 (green) however was occasionally used to improve contrast for photographs and if used indicated in each legend. The collected data for Appendix 7 was obtained using SRF#2 and CSF#1 combinations only. Probe 6NA from unlimed soil at 30-40 cm depth in spring 1999. Cx. 1000x. Photo 8-5, SRF#2 (green) + CSF#1(clear), 3 second exposure.

12 -2



Appendix 12-3: Boletus edulis

Fruiting Body Occurrence: Fruiting bodies were very commonly found in both limed and unlimed forest in the fall of 2001 (Appendix 2A)

Mycorrhizal Occurrence: Mycorrhizae were present in large numbers in the wet year (2000) but less common than expected based upon the abundance of fall fruiting bodies. Mycorrhizae were present primarily at 0-10 cm depth, but also found at 30-40 cm depth, but at 50-60 cm depth they were found only in unlimed soil (Appendix 7-3, Appendix 8A-Graph B3-3). Rhizomorphs were more common in the unlimed soil samples at all depths and tended to survive cryosectioning better implying better vigor than in the limed probes. Since very few mycorrhizae were isolated in 1999 it can be concluded that this mycorrhiza prefers moist soil and is absent or present only in its vegetative (spore) form in dry soil.

Morphology: Refer to Agerer (1987-1998), plate 36. (Figure 12-3A, B).

Fungal Autofluorescence: Rhizomorphs in unlimed soil fluoresced yellow green at 0-10 and 30-40 cm depth but were faint yellow at 50-60 cm (Appendix 7-3). Rhizomorphs from the limed probes did not survive cryosectioning to be distinguishable from other cellular debris. Mantle fluorescence was variable but generally orange-yellow to yellow-green (Figure 12-3). In unlimed soil, the mantle was yellow-orange (<1 mm) to yellow-green (>5 mm) in spring to consistently faintly orange-yellow in fall at 0-10 cm depth, bright yellow-green at 30-40 cm depth, and yellow at 50-60 cm depth. In limed soil, the mantle was very faintly yellow-green in spring to faintly orange (<1 mm) or faintly yellow (>5 mm) in the fall at 0-10 cm depth, and at 30-40 cm depth it was very faintly orange-yellow. The Hartig net and corresponding epidermal/hypodermal root cells generally fluoresced faint orange except at 50-60 cm depth in the unlimed probe where they were green (<1 mm) to yellow-green (>5 mm) in fall 2000. The fainter autofluorescence and color variations in limed probes imply a physiological change associated with the liming. A loss of fluorescing wall chemicals implies a change in wall integrity, which would correspond to the subjective observation that the probes from the limed soil appeared less vigorous and healthy in general appearance.

Root Autofluorescence: The xylem had a blue autofluorescence. While the phloem was usually non-fluorescent, in fall 2000, in one probe (0-10 cm depth, limed soil) the phloem had an orange cast and in another it was yellowish (50-60 cm depth, unlimed soil). The pericycle and endodermis typically were blue to green-blue (0-10 cm depth, limed soil, fall 2000) to green (50-60 cm depth, unlimed soil, fall 2000). The cortex was generally faint (0-10 cm depth) to bright yellow-green (30-40 and 50-60 cm depth) in unlimed soil while in limed soil it was bluish-yellow (0-10 cm depth, spring) to faint yellow (0-10 cm depth, fall) to blue (30-40 cm depth). In combination with *Boletus edulis* , fine oak roots varied slightly in autofluorescence depending on depth, season and liming factors.

Fungal Aluminum: The Rhizomorphs and mantle isolated from unlimed and limed soil had both negative and positive reactions to Morin indicating some inconsistent Al-sequestration with no distinct pattern other than the mantle tended to have more Al present as depth in soil increased in some cases. The region of the Hartig net was primarily Al-free at 0-10 cm depth with a faint positive in limed soil at 30-40 cm depth and at 50-60 cm depth in unlimed soil.

Root Aluminum: Aluminum was consistently absent from the phloem, pericycle, and endoderm cell walls. In unlimed soil, at 0-10 cm depth in the fall of 2000, all the root tissues and fungal tissues from various mycorrhizal samples lacked Al < 1 mm from the tips but at > 5 mm from the same tips, Al was found in the xylem and on the outer (cortical side) of the endodermal walls and in small amounts in the epidermal region of the Hartig net and the outer mantle. In spring samples from 30-40 cm depth, Al was moderately present in the xylem, mantle and rhizomorphs but strongly present in the cortex. At 50-60 cm depth in fall samples, Al was strongly present in the xylem, cortex and variably in the mantle and questionably in the rhizomorph. In limed probes, in the spring in probes from 0-10 cm depth, Al was less abundant in xylem, cortex and mantle near the tips (<1 mm) and more abundant in older growing areas (>5 mm). In the fall of the same year Al was consistently abundant in the xylem and cortex but absent from the mantle. In probes from 30-40 cm depth, Al was present in the xylem, less so in the cortex and inner Hartig net area but faintly present in the outer mantle areas.

Summary: Despite variability, implying a highly dynamic system, some general trends seem evident. The major trends were: (1) a slow continuous internal movement of Al ions (2) Xylem Al-concentration increased with soil depth and (3) Al concentration increased in the fall. (4) Al concentration was higher in the older xylem (5) more Al in limed roots.

In *Boletus edulis* mycorrhizae, Al uptake was more evident in older, perhaps slower growing regions than in the expanding tip areas. . *Boletus edulis* acted as a barrier to Al uptake when young, not by sequestration since Al did not accumulate in the fungal walls, but by physiological barriers which could include: inhibited uptake, active extrusion, lack of portals or tight apoplastic connections. With mantle aging, exposure time, or increased acidification damage, Al slowly "leaked" into the root where it eventually entered the cortex. In addition, depth affects uptake where, although the mantle had little Al, the Al slowly translocated via apoplastic pathways to the cortex where it was temporarily halted by the endodermal barrier and so tended to accumulate. But some how it transgressed this barrier (via incomplete casparian zones?) and reached the xylem where it slowly accumulated to saturation and was then potentially translocated to other plant regions. The presence of Al may have been affected by microenvironmental factors. For example, if the mycorrhizal tip grows into a tiny buffered pocket where there is no free Al, the roots would be Al-free, but as buffering capacity was lost, especially in deeper soil, and more Al was present, then more Al could accumulate. As the pH drops further, the Al held in the root and mycorrhizal cells may be freed to translocate to aerial plant zones.

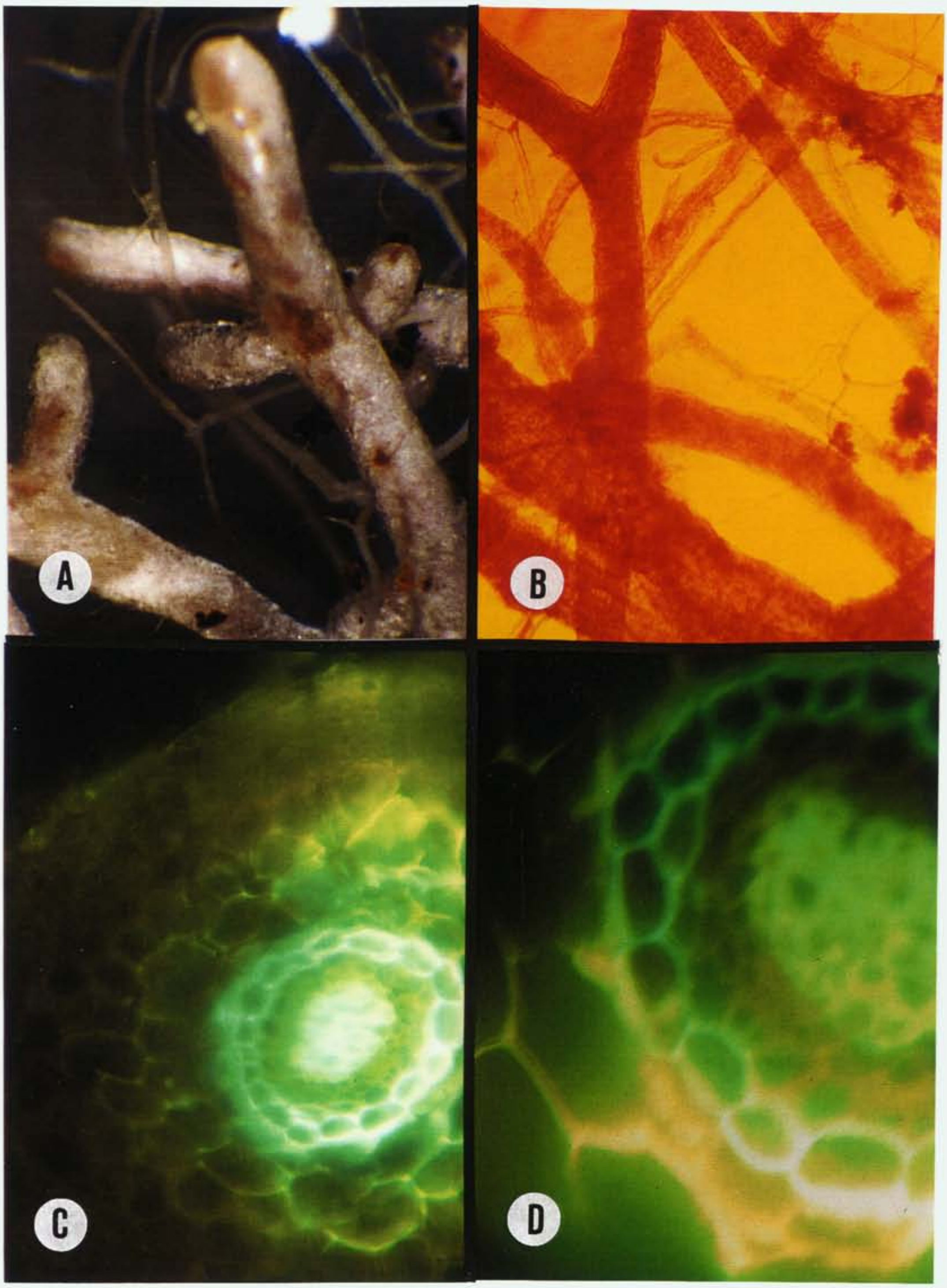
Figure 12-3A: *Boletus edulis* gross morphology. A portion of the monopodial-pyramidal mycorrhizal system with bent axes and 60^0 branched rhizomorphs is visible. The mantle is silvery due to air pockets. Probe collected 15 May 2000 from unlimed forest. 160x. Photo 1-25.

Figure 12-3B: *Boletus edulis* rhizomorphs. The rhizomorph shows typical "Y" branching form with numerous smaller hyphal emanations. Probe 200N from unlimed soil to 30-40 cm depth in spring 2000. 40x. Photo 40-23, white light, 2 second exposure.

Figure 12-3C: *Boletus edulis* autofluorescence < 1 mm from tip. The thick outer mantle is dull green while the root cells vary from dull to bright blue. Probe 1000K from limed soil at 0-10 cm depth in fall 2000. Cx. 400x. Photo 22-3, clear filter, 15 second exposure.

Figure 12-3D: *Boletus edulis* with Morin, < 1 mm from tip. Aluminum has accumulated in a large abound in the cortical cells adjacent to the endodermal barrier. Some Aluminum is evident inside the stele in the phloem walls but none in present in the central xylem region. Probe 1000 K, from limed soil at 0-10 cm depth in fall 2000. Cx. 400x. Photo 22-5, clear filter, 60 second exposure, 5 minutes after treatment.

12-3



Appendix 12-4: Byssocorticium atrovirens

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare, most samples collected spring (unlimed) and fall (limed) 2000 from 0-10 cm depth (Appendix 8A-B3-4) Only probe from 30-40 cm depth from unlimed fall 2000 was used for fluorescence testing (Appendix 7-4).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 51. This mycorrhiza was easily recognized by its steel-blue mantle and cottony hyphal envelope (Figure 12-4A).

Fungal Autofluorescence: *Byssocorticium atrovirens* mantle and hyphae were bluish at <1 mm (Figure 12-4C) and non-fluorescent at > 5 mm. The Hartig net walls were orange to pale orange (Figure 12-4B, C).

Root Autofluorescence: The pericycle, endodermis and cortex were blue in fluorescence while the xylem was pale yellow and the phloem was non-fluorescence (Figure 12-4B).

Fungal Aluminum: Aluminum was not truly evident in the mantle or emanating hyphal walls but both had green specks present in the vicinity of the walls and an overall change in fluorescence from blue to green at least at < 1 mm from the tip (Figure 12-4B, D). The green fluorescence was variable at > 5 mm. The Hartig net cells however definitely had some aluminum present typified by a yellower fluorescence in some sections.

Root Aluminum: Aluminum was absent from the xylem, phloem, pericycle and endodermis but modestly present in the cortex at <1 mm from the tip. At > 5 mm from the tip aluminum was definitely present in the xylem and variably presenting the cortex.

Summary: It seems that older root zones, where the mycorrhizal mantle was thinner, had more aluminum present. *Byssocorticium atrovirens* mantle apparently provides no barrier to aluminum uptake. The fungal cells in the Hartig net region however may be sequestering aluminum, affecting its uptake. Aluminum seems to be complexing on small grains (phosphate exudates??) located in the mantle.

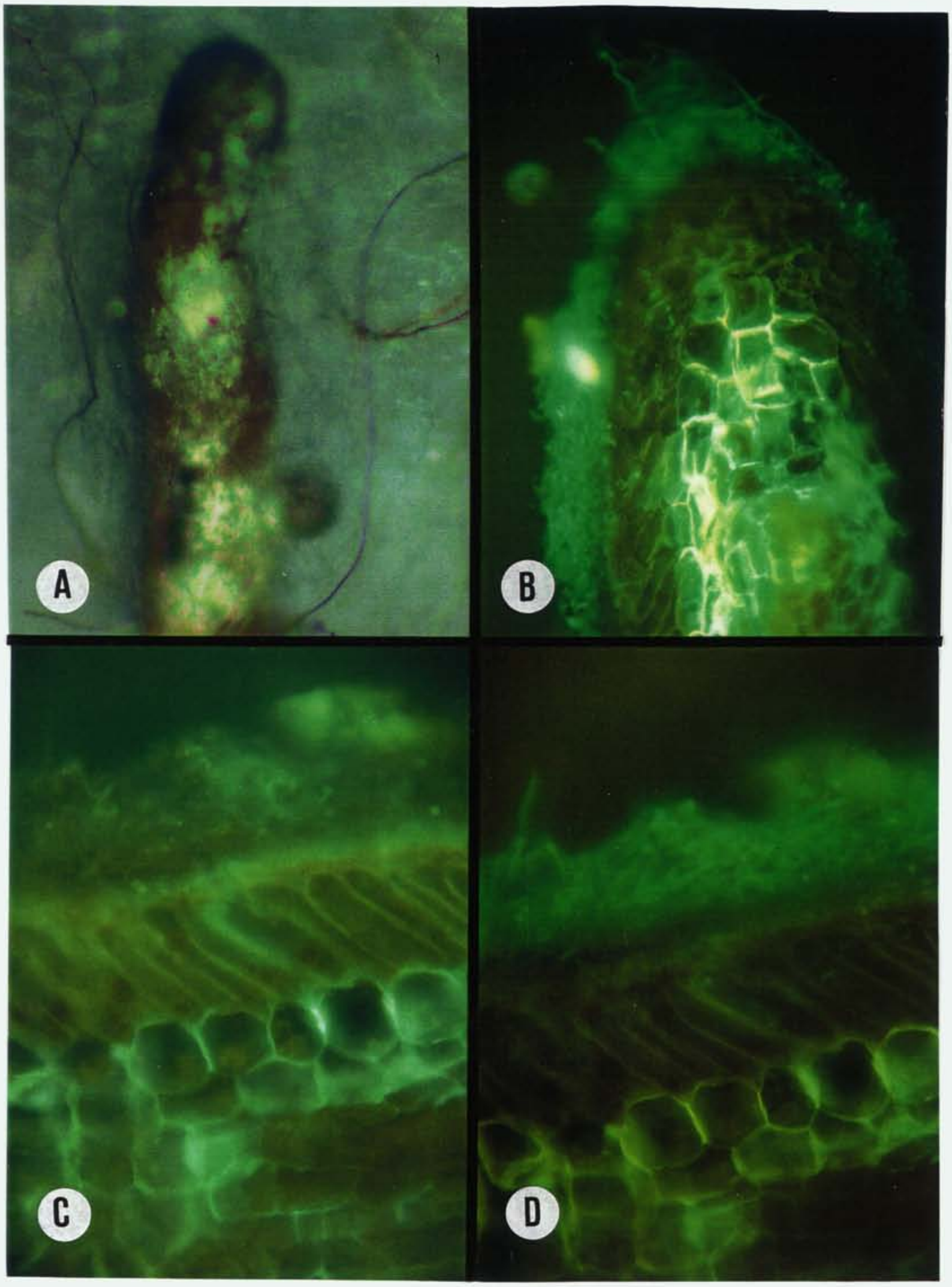
Figure 12-4A: ***Byssocorticium atrovirens*** **gross morphology.** The steel blue silvery mantle is surrounded by a halo of fine white-blue emanating hyphae. Probe 100N from unlimed soil at 0-10 cm depth in spring 2000. 300x. Photo 3-17.

Figure 12-4B: ***Byssocorticium atrovirens*** **with Morin, tip.** The mantle and emanating hyphae fluoresce more intense green but only a small area of the cortex has traditional yellow fluorescence indicating aluminum. The (inactive?) meristem was Al-free. Probe 1100 N from unlimed soil at 30-40 cm depth, fall 2000. Lx. 250x. Photo 21-14, clear filter, 30 second exposure, 7 minutes after treatment.

Figure 12-4C: ***Byssocorticium atrovirens*** **autofluorescence, < 1 mm from tip.** The loose mantle is green but the fungal cells in the Hartig net are green-orange. The cortical cells are typical blue. Probe 1100 N from unlimed soil at 30-40 cm depth. Lx. 400x. Photo 21-11, clear filter, 8 second exposure.

Figure 12-4D: ***Byssocorticium atrovirens*** **with Morin, < 1 mm from tip.** The mantle shows intense green fluorescence indicating weak Al complexing while the Hartig net is Al-free and the cortical cells show some typical yellow developing. Probe 1100 N from unlimed soil at 30-40 cm depth. Lx. 400x. Photo 21-15, clear filter, 30 second exposure, 7 minutes after treatment.

12-4



Appendix 12-5: Cenococcum geophilum

Fruiting body Occurrence: No known fruiting bodies.

Mycorrhizal Occurrence: Extremely common at all depths (but especially at 0-10 cm), seasons and soil types (Appendix 7-5 and Appendix 8A-B3-5). *Cenococcum geophilum* was the most successful mycorrhizal species in both the unlimed and limed forests. Spore balls (Sclerotia) were found in nearly all probes sampled, but were especially common in the limed soil in the very dry fall of 1999 at 0-10 cm depth, and in unlimed soil in spring 2000 at 30-40 and 50-60 cm depths (Figure 12-5 B, D). Increased production of spore balls was associated with desiccation stress (limed forest) and with depth (unlimed forest).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 11. (Figures 12-A, B, C, D, E). Unlike the long, somewhat hairy tips of the black mycorrhizae *Fagirhiza setifera* and *Fagirhiza spinulosa,* the tips of *Cenococcum* were short and stubby with numerous thick black emanating hyphae of all approximately the same length. A system of *Cenococcum* typically looked like a ball of stones on the root with the stones tightly held by a halo of thick black hyphae. Tight adhesions make the system very difficult to clean but provided excellent fungi-soil mineral interfaces.

Fungal Autofluorescence: The mantle and numerous hyphal hairs were non-fluorescent. Hartig net fungal cells were non-fluorescent, but the adjacent hypodermal and epidermal root cells at the fungal-root interface were variable from being non-fluorescent to blue, bluish-green, bluish-orange, greenish-blue, bluish-yellow, yellowish-orange to orange with cells closer to the tip tending to be bluer or less obviously fluorescent than cells further from the tip, but this was not consistent for all samples (Figure 12-6F, I).

Root Autofluorescence: The xylem was usually blue (Figure 12-5I, J, M) with some exceptions, especially in wet fall 2000 when in unlimed soil some samples were yellow-green (0-10 cm depth) (Figure 12-5F) to green (30-40 cm depth) . The phloem was non-fluorescent in all samples, except in limed soil at 30-40 cm depth where it had an orange (spring 1999) to faint orange (fall 1999) fluorescence and at 50-60 cm depth where it was faint orange (fall 1999). This orange coloration, which was not shared by mycorrhizal roots from unlimed soil, may be a response to desiccation stress. The pericycle and endodermal cells were usually blue to bight blue in fluorescence. However in the fall of 2000, in some unlimed soil samples there was variation in the autofluorescence from non-fluorescent (< 1 mm from tip) to occasionally greenish (0-10 cm to 30-40 cm depth) while some limed probes exhibited a blue-green fluorescence (50-60 cm depth). The cortical cells were usually blue. In limed soil in the spring of 1999 the cortical cells were yellow-green (0-10 cm depth) and green (30-40 cm depth). In unlimed soil in the fall of 1999, the cortical cells were yellow (0-10 cm depth) and occasionally faint yellow (50-60 cm depth), and in the fall of 2000 the cortical cells had a yellow-green (0-10 cm depth), greenish yellow (30-40 cm depth) or bluish-green tinge (50-60 cm depth). The underlying autofluorescence in root cells was blue (Figure 12-5I), but nearer the tip the meristem tended to have an orange cast while the tip cells were green-blue (Figure 12-6F).

Fungal Aluminum: The walls of the mantle and numerous emanating hyphae were Al-free in all cases, except for the fall of 2000 when in limed soil, at 30-40 cm depth, some specks of Al were present. In the Hartig net region Al was primarily absent in the unlimed soil probes (Figures 12-5I, J) with some exceptions: Spring and fall 1999 at 50-60 cm depth some Al was present in areas < 1 mm from the tip, and in the spring of 2000 some Al was evident >5 mm from the tip in the 0-10 cm depth samples, and in the fall of 2000 Al was definitely present in the Hartig net (0-10 cm depth and 50-60 cm depth). In limed soil, Al was absent from the outer mantle but evident (but highly variable) in the Hartig net area (Figure 12-6H, K, L, N) with generally more Al at 50-60 cm depth.

Root Aluminum: The xylem contained Al in all samples except in fall 2000 when Al was absent in some roots from 0-10 cm depth in both limed and unlimed soil samples (Figure 12-5I, J). In spring 1999, at 30-40 cm depth in limed soil, some xylem cells were also Al-free. The phloem cell walls were Al-free, but sometimes in limed soil the cytoplasm showed Al content (Figure 12-5N). The pericycle and endodermal cell walls were Al-free except for one probe from 30-40 cm depth from limed soil in spring 2000. On occasion the cortical sides of the endodermal walls contained Al (0-10 cm depth, spring 1999 and fall 2000 in unlimed soil) but otherwise were Al-free. The cortical cell walls contained variable amounts of Al. In unlimed soil probes, the Al content increased seasonally with more present in the dry fall at 0-10 cm depth than in the wet fall. At 30-40 cm depth the Al content was higher in the spring of 1999 than in fall but the following spring 2000, only spores were present at this depth in the unlimed soil. At 50-60 cm depth Al was notably absent from many samples regardless of the season in the unlimed probes. In limed soil probes, Al was often absent at < 1 mm but present at > 5 mm from the tip in 0-10 cm depth probes (spring & fall 2000) and at 30-40 cm and 50-60 cm depths (fall 1999). Otherwise in limed soils, Al was more prevalent in 30-40 (Figure 12-5E, F, G) and 50-60 cm depth samples than at 0-10 cm depths (Figure 12-5K, L, N).

Summary: In general, *Cenococcum geophilum* mantles neither contained Al nor acted as a barrier to Al movement into the root. In fact, the mantle and emanating hyphae may actually have promoted uptake and acted as conduits to the Hartig net interface. The Al content of the cortical cells increase seasonally and with distance from the mycorrhizal tips. Qualitatively, more Al was present in fine roots from limed soils than from unlimed soils. With the enormous surface area provided by *Cenococcum geophilum,* and the strong cortical accumulations, it was expected that the ion uptake and Al accumulation would be the highest of all the species examined. Subsequent mineral analysis confirmed this. Since this species did not store Al, but allowed or promoted its translocation to the cortex. The ectomycorrhizae must either contain an excellent extrusion system to remove Al from the fungal cells, or more likely a good filter system that prevents Al uptake into the symplast and thus protects the mycorrhiza from the toxic effects of the ion. Under more alkaline soil conditions where Al is less available, *Cenococcum* would be an excellent symbiont providing the root with abundant essential elements, but it is not selective against Al. In acidic soils with abundant freed Al ions, *Cenococcum geophilum* survives exceedingly well since it does not accumulate Al, but it also does not block apoplastic movement of the toxic ions into fine host roots.

Figure 12-5A: ***Cenococcum geophilum*** **gross morphology.** Short mycorrhizal tips with many thick wavy hyphae emanating from a shiny black mantle. The density of the emanating hyphae was greater prior to cleaning out adhering debris to expose the mantle. Probe collected 17-May-2000 from unlimed forest at 0-10 cm depth. 210x. Photo 2-12.

Figure 12-5B: ***Cenococcum geophilum*** **gross morphology & spore ball.** Two mycorrhizal tips can be seen to the left and the black shiny, rough surfaced spore ball is visible at the bottom right. These spherical sclerotia were often weakly attached to the root via hyphae. The spore balls were more common in deeper soil and during dry periods. Probe 200K from limed soil at 30-40 cm depth in spring 2000. 250x. Photo 4-11.

Figure 12-5C: ***Cenococcum geophilum*** **mantle.** The outer mantle hyphae are arranged in a star-like pattern, with cross walls less conspicuous than lateral walls. Several deeper layers are visible through the outer mantle cells. Probe 6KA from limed soil at 0-10 cm depth in spring 1999. Surface. 1000x. Photo 12-19, white light, 120 second exposure.

Figure 12-5D: ***Cenococcum geophilum*** **spore ball section.** The inside of the spore balls show tightly clustered cells in an amorphous arrangement. filled with dark contents. Some cells appear empty due to sectioning procedure. Probe 1100 N from unlimed soil at 0-10 cm depth. Cx. 1000x. Photo 16-24, white light, 15 second exposure.

Figure 12-5E: ***Cenococcum geophilum*** **tip.** In natural light, the mantle and hyphae of Cenococcum are deep black with a minimal Hartig net region at the tip. Despite the lack of penetration hyphal strands, the outer root cells are already elongated in a modification typical for many ectomycorrhizae. Probe 6KA from limed soil at 0-10 cm depth in spring 1999. Lx. 400x. Photo 12-20, white light, 2 second exposure.

Figure 12-5F: ***Cenococcum geophilum*** **autofluorescence at tip, Limed.** The fungal cells are non-fluorescent while the root tip id blue-green except for the orange-yellow meristem zone. The central cylinder is open-ended in this extension area and the endodermis and pericycle are poorly developed. Probe 6KA from limed soil at 0-10 cm depth in spring 1999. Lx. 400x. Photo 12-21, clear filter, 15 second exposure.

Figure 12-5G: ***Cenococcum geophilum*** **with Morin at tip, Limed.** Aluminum is strongly present in the meristem, xylem and inner cortical cells. Probe 6KA from limed soil at 0-10 cm depth in spring 1999. Lx. 400x. Photo 12-23, clear filter, 15 second exposure, 10 minutes after treatment.

Figure 12-5H: ***Cenococcum geophilum*** **with Morin, < 1 mm from tip, Limed.** The outer mantle lacks Aluminum, but in the Hartig net region, some aluminum is present in the penetrating hyphal cell walls and the outer cortical walls. The accumulation of small amounts of aluminum may be associated with damaged tissues. Probe 1000K from limed soil at 30-40 cm depth in fall 2000. Cx. 1000x. Photo 16-28, clear filter, 90 second exposure, 5 minutes after treatment.

Figure 12-5I: *Cenococcum geophilum* autofluorescence < 1 mm from tip, Unlimed. The mantle is non-fluorescent and so barely visible outside the strongly blue fluorescent cortex. The stele is dull blue in the center surrounded by bright blue regularly shaped endodermal cells. There is no apparent Hartig net nor any pericycle in this region close to the tip. Probe 1NA from unlimed soil at 0-10 cm depth in spring 1999. Cx. 250x. Photo 4-29, clear filter, 25 second exposure.

Figure 12-5J: *Cenococcum geophilum* with Morin, < 1 mm from tip, Unlimed. There is no evidence of aluminum anywhere even after 30 minutes of treatment. To be absolutely sure, the test was repeated with fresh reagent and new sections but there was no change. Probe 1NA from unlimed soil at 0-10 cm depth in spring 1999. Cx. 250x. Photo 4-33, clear filter, 30 second exposure, 30 minutes after treatment.

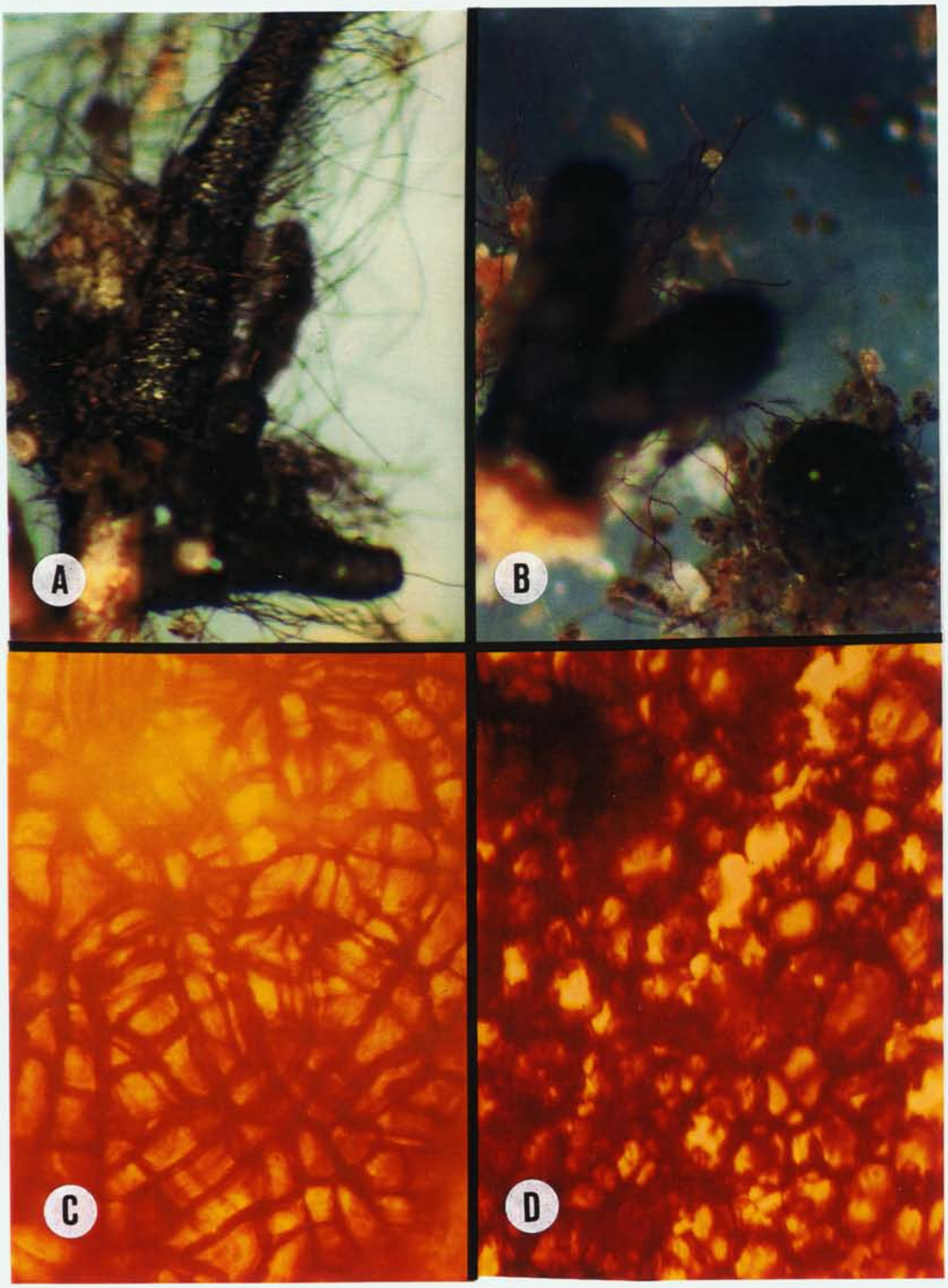
Figure 12-5K: *Cenococcum geophilum* with Morin, < 1 mm from tip, Limed. Aluminum is absent from the mantle but present weakly in the Hartig net and strongly present in the outer cortical cells but not the inner cortical cells or the central cylinder. Probe 1K from limed soil at 0-5 cm depth, spring 1999. Cx. 400x. Photo 6-7, clear filter, 29 second exposure, 5 minutes after treatment.

Figure 12-5L: *Cenococcum geophilum* with Morin, < 1 mm from tip, Limed, later. The Hartig net and outer mantle are bright green when using a green filter indicating Al is present but the inner cells still fluoresce blue. Probe 1K from limed soil at 0-5 cm depth, spring 1999. Cx. 400x. Photo 6-8, green filter, 10 second exposure, 30 minutes after treatment.

Figure 12-5M: *Cenococcum geophilum* with Morin, blue filter. This photo is included to demonstrate that the proper filter combination is essential in assessing aluminum reactions. The yellow fluorescence is totally masked here. Probe 1K from limed soil at 0-5 cm depth. Cx. 1000x. Photo 6-16, blue filter, 60 second exposure, 30 minutes after treatment.

Figure 12-5N: *Cenococcum geophilum* with Morin, green filter. When using a green filter, or none at all, yellow fluorescence is highly evident in the Morin-Al reaction. The green filter can add contrast to improve visibility of the aluminum depositions. In this case, Aluminum is very evident in the ropy fungal cells in the Hartig net (right side) and in the outer walls of the single layer of outer cortical cells. The single layer of endodermal cells is Al-free but inside the central cylinder, several cells can be seen with cytoplasmic accumulations of aluminum. Somehow the aluminum has crossed the endodermal barrier and since this region is very close to the root tip, the access point was most probably in the meristem region. 1K from limed soil at 0-5 cm depth. Cx. 1000x. Photo 6-10, green filter, 5 second exposure, 30 minutes after treatment.

12-5



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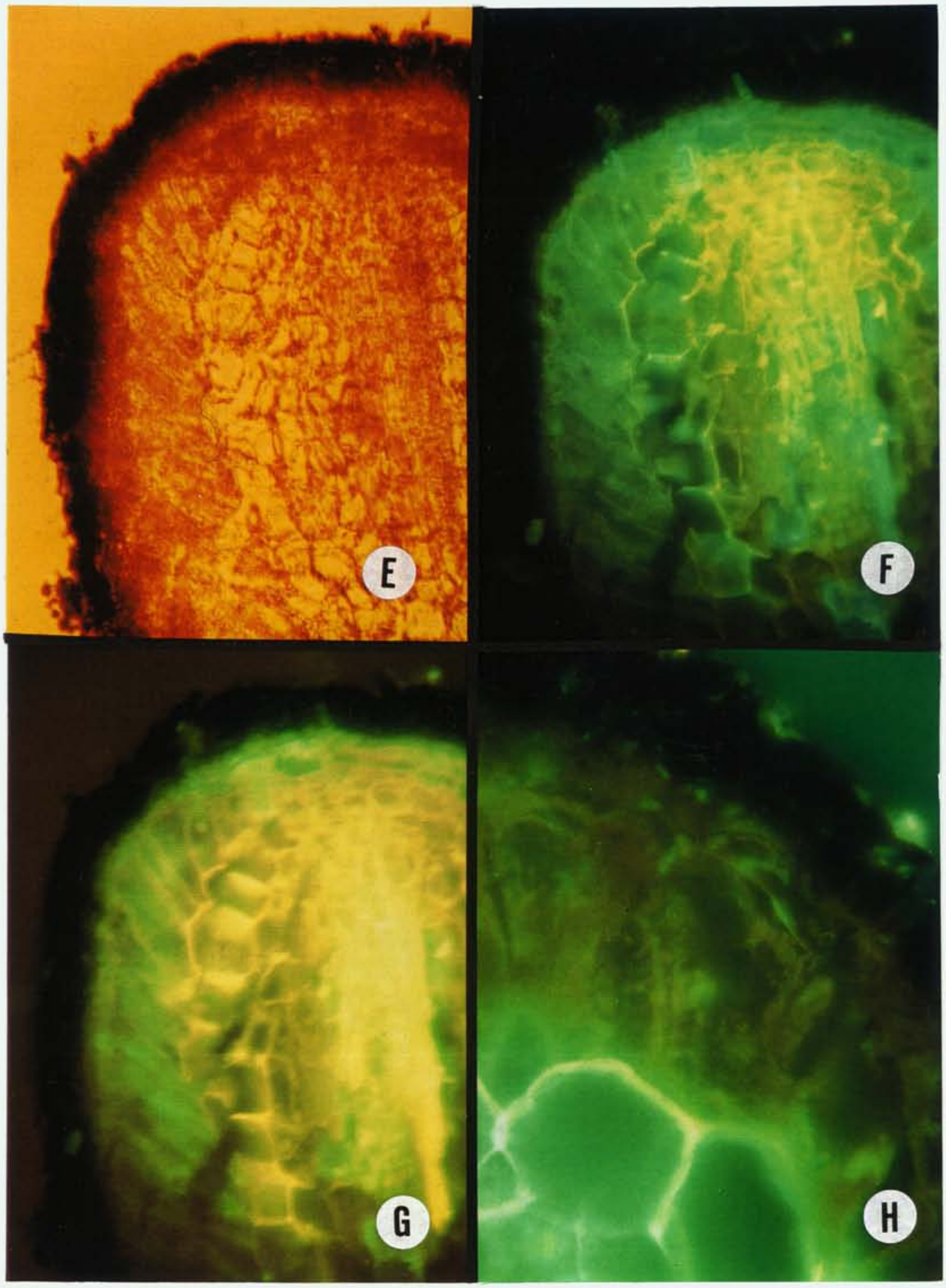

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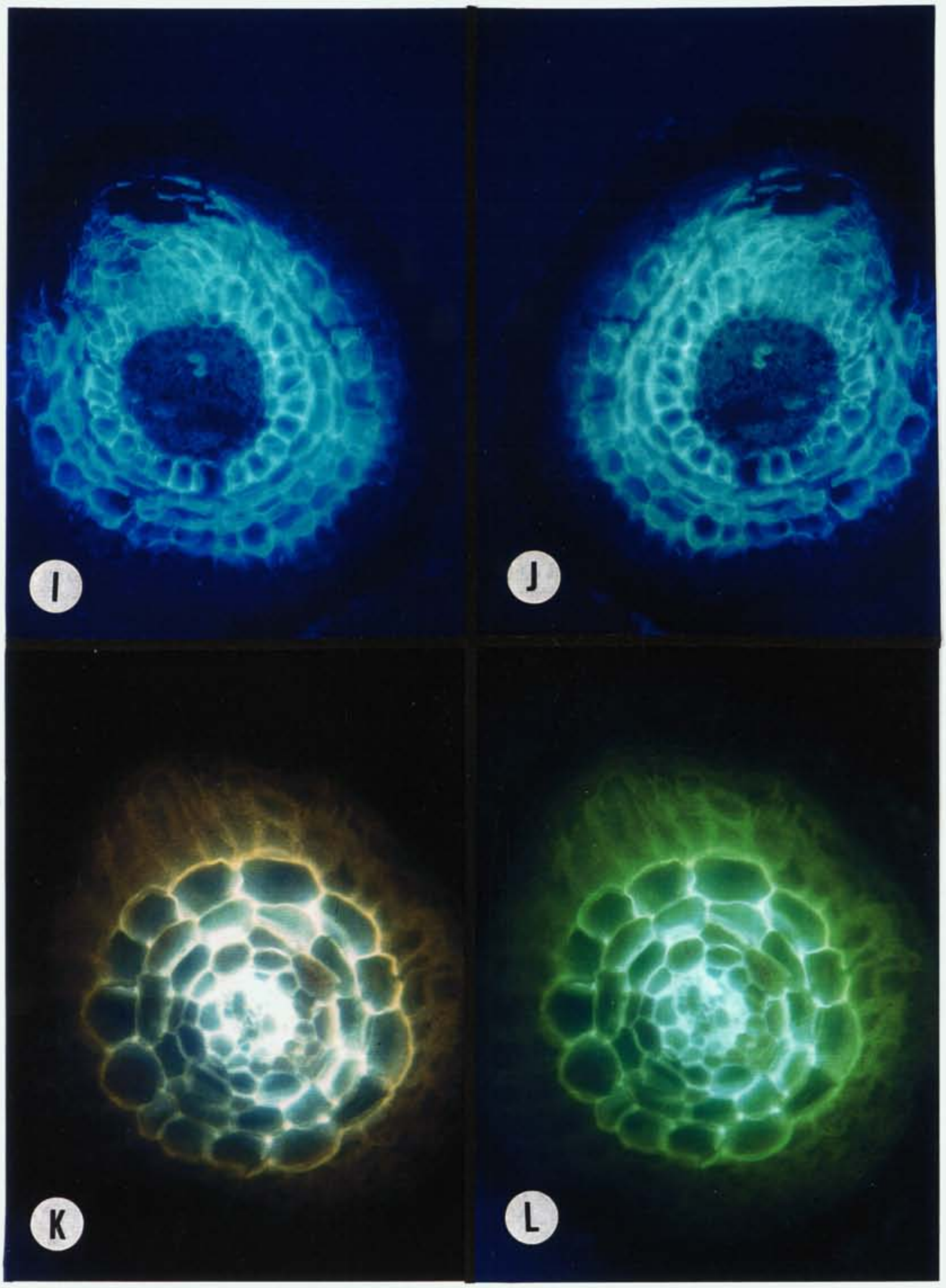
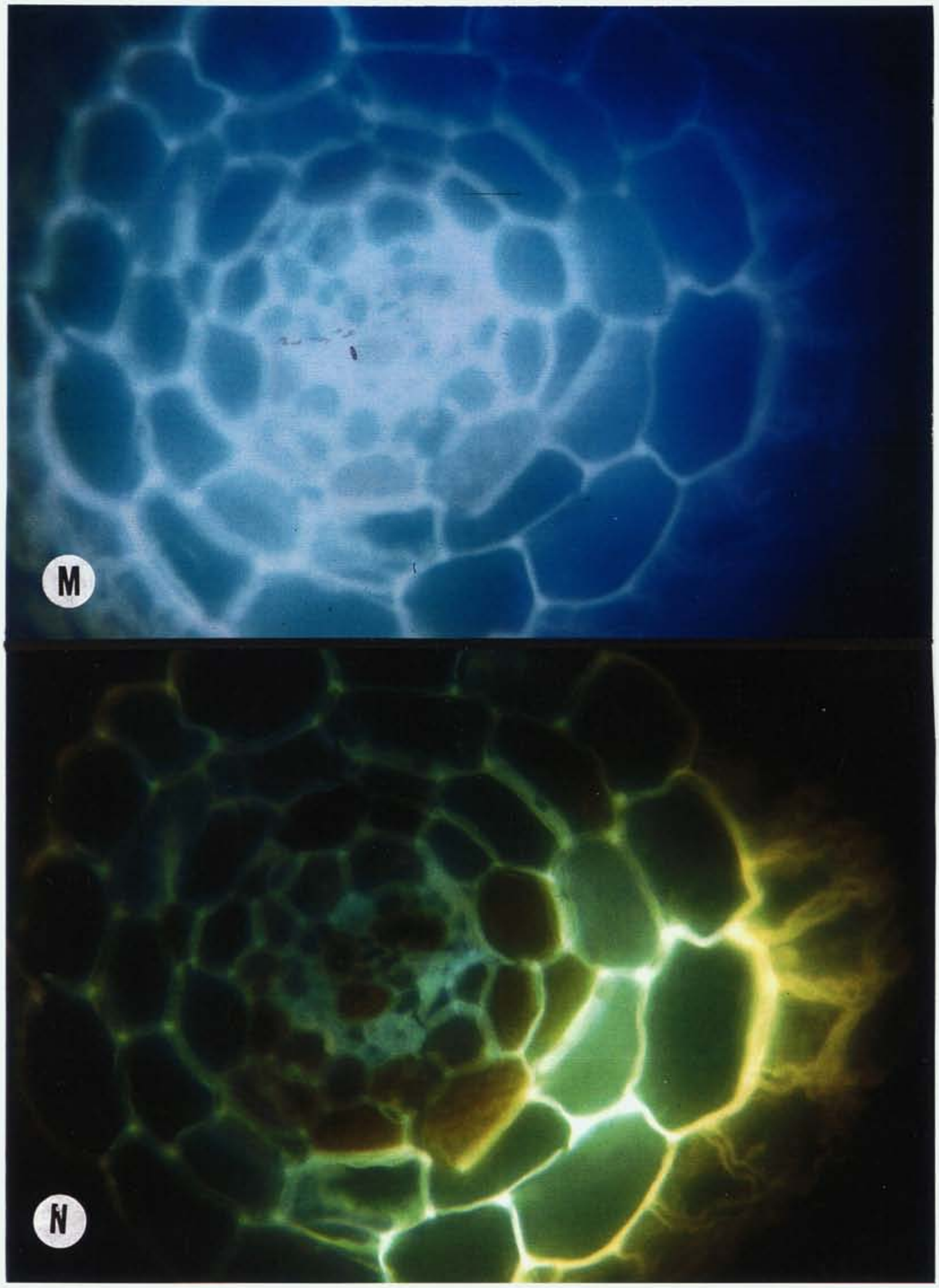


12- 5



Appendix 12-6: Cortinarius armillatus

Fruiting body Occurrence: Fruiting bodies of an unknown *Cortinarius* species were present in fall 2000 in the limed plot. In fall 2001 *Cortinarius pallustris* and *Cortinarius pholideus* were collected from the unlimed plot (Appendix 2C).

Mycorrhizal Occurrence: Mycorrhizae were present primarily in the moist fall of 2000, but were more common in limed soils at 0-10 cm depth (Appendices 7-6 and 8A-B3-8).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 52. (Figure 12-6A). Cortinarius was most easily recognized by the tufts of fine white rhizomorph frequently extending from near the mycorrhizal tips.

Fungal Autofluorescence: In unlimed soils the mantle autofluorescence varied from blue to faint yellowish-blue to yellowish-green to orange-yellow to orange often being more bluish closer to the tip. The cystidia were fainter or more orange in tint compared to their associated mantles. Emanating hyphae were orange. The Hartig net was similar to the mantle but tended to be fainter with a bluish tendency (0-10 cm depth) or an orange tendency (30-40 cm depth). The fungal colorations were consistent within each probe sampled, but varied from site to site, probably dependent upon specific microenvironmental variations in micronutrition and moisture which could explain, in part, the absence of sensitive morphotypes from probes taken in the very dry 1999 seasons. In limed soils, the mantle, cystidia, hyphae and Hartig net walls were consistently orange (0-10 cm depth) or green (30-40 cm depth)(Figure 12-6A), with the lack of variation implying a more consistent soil mineral composition. But, since the mycorrhizal abundance was lower than in the unlimed soils, it might be assumed that although the soil composition was more stable, it was not ideal.

Root Autofluorescence: The xylem autofluoresced blue except for one tip (0-10 cm depth unlimed soil) where it was faint yellow. The phloem was non-fluorescent except for one tip (30-40 cm depth from unlimed soil) where it was faint yellow. The pericycle was either non-fluorescent (undeveloped) or blue (developed). The endodermis was faint or bright blue except for one tip from 30-40 cm depth in limed soil where the immature endodermis was non-fluorescent at <1 mm from the tip. The cortex autofluorescence matched that of the mantle (blue to orange, at 0-10 cm depth) in both limed or unlimed soils, but at 30-40 cm depth, the cortex fluoresced blue an only occasionally matched the variable mantle autofluorescence. *C. armillatus* was present primarily on immature root tips implying that it may be very limited in its ineffective ability requiring very young, fresh moist tips. The unusual immaturity of the pericycle and sometimes the endodermis at > 5 mm from the tip, especially in fall probes, combined with the distinctive similarities in cortical wall and mantle autofluorescence may be due to unknown bioactive substances exuded from *Cortinarius armillatus* which may act to slow maturation of infected roots making them more suitable for colonization.

Fungal Aluminum: In the unlimed probes, the mantle, cystidia and emanating hyphae were Al-free, with the exception of one tip found at 0-10 cm depth. In the limed probes Al was present in the mantle at 0-10 depth and questionably present at 30-40 cm depth.

Root Aluminum: In the unlimed probes, the roots at 0-10 cm depth were Al-free, with the exception of one tip found at 0-10 cm depth where Al was present in the mantle, cystidia, hyphal strands, xylem and cortex. This tip was more mature than the other tips, as evidenced by a blue autofluorescence in the pericycle and endodermal cell walls. At 30-40 cm depth, in unlimed soil, Al was strongly present in the xylem, cortex, hypodermal and epidermal walls, but absent from the mantle. In limed probes at 0-10 and 30-40 cm depths, Al was present in the xylem and cortex but not elsewhere (Figure 12-6B).

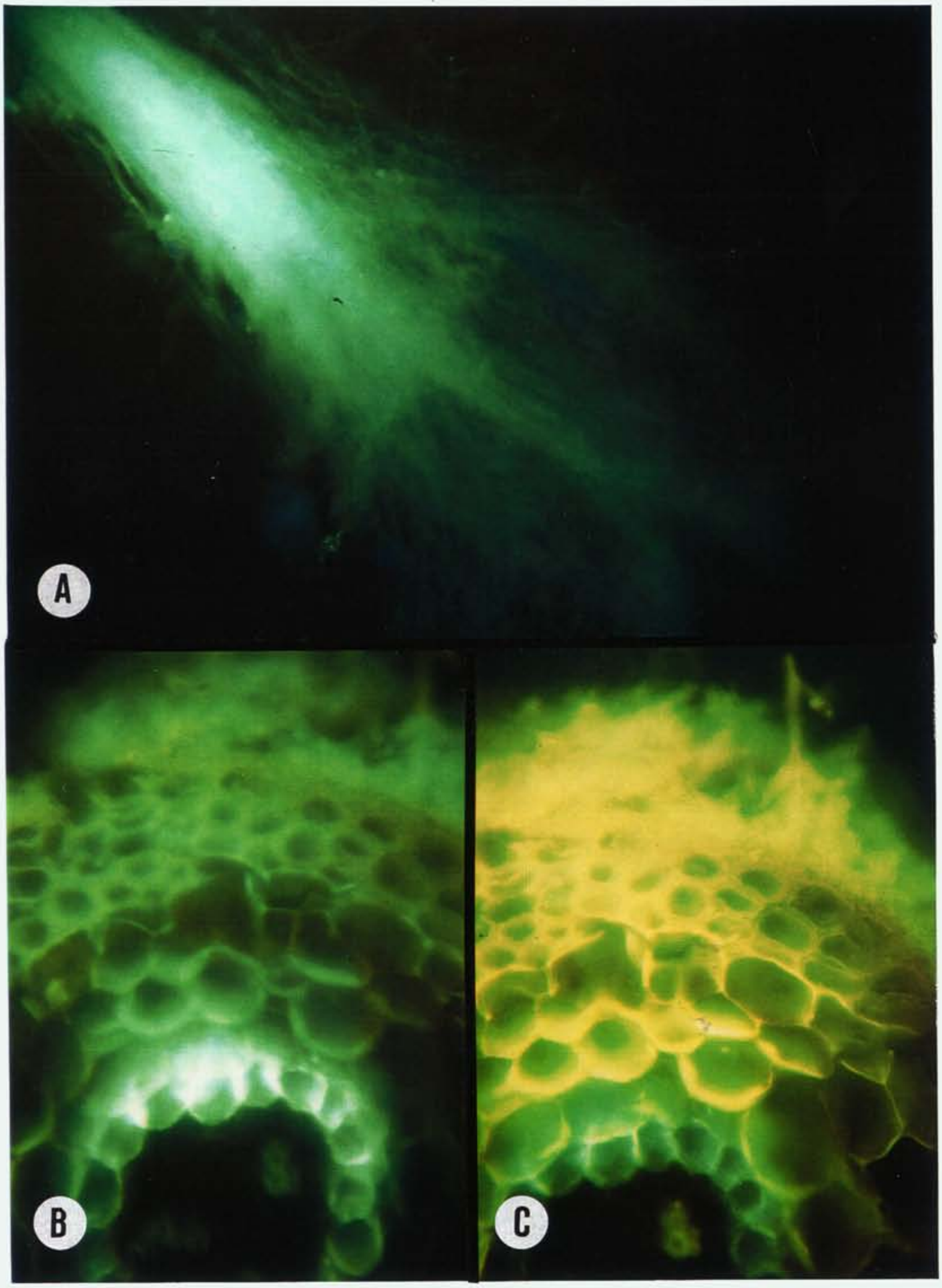
Summary: *Cortinarius armillatus* is a very sensitive mycorrhizal species that requires young fine roots and ideal environmental conditions to survive which would explain its absence during desiccation stress and at depths greater than 30-40 cm. It seems to have some ability to maintain roots in an immature state by affecting cell wall composition. Upon aging, or at greater depths, it loses its ability to prevent Al uptake.

Figure 12-6A: *Cortinarius armillatus* young rhizomorph. The rhizomorphs were usually orange in unlimed and limed soil at 0-10 cm depth but at 30-40 cm depth (in limed soil only) they were green. Probe 6KA from limed soil at 30-40 cm depth. 250x. Photo 11-26, clear filter, 20 second exposure.

Figure 12-6B: *Cortinarius armillatus* autofluorescence < 1 mm from tip. The endodermal ring is bright blue, but the inner peridermal ring is non-fluorescent. The cortical and fungal cells have matching greenish autofluoresence. Probe 6KA from limed soil at 30-40 cm depth. Cx. 400x. Photo 12-8, clear filter, 15 second exposure

Figure 12-6C: *Cortinarius armillatus* with Morin < 1 mm from tip. All cell walls outside of the stele strongly contain aluminum. Probe 6KA from limed soil at 30-40 cm depth. Cx. 400x. Photo 12-10, clear filter, 15 second exposure, 10 minutes after treatment.

12-6



Appendix 12- 7: Cortinarius bolaris

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rarely found at only 30-40 cm depth in spring 1999 and fall 2000 in unlimed soil but found at 0-10 cm (spring 1999) and 30-40 cm (fall 2000) depth in limed probes (Appendices 7-7 and 8A-B3-9).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 67.

Fungal Autofluorescence: The mantle and hyphal autofluorescence was variable even within single samples. In unlimed soil the mantle and Hartig net was orange to blue green. In limed soil the mantle and emanating hyphae were blue to orange to faint yellow but non-fluorescent in some mature root zones, but the Hartig net zone was either blue (< 1 mm, spring 1999) or orange (fall 2000) in tone (Figure 12-7A).

Root Autofluorescence: Typical, except in unlimed roots the phloem cell walls were very faint orange, and, in spring 1999, the limed roots, the xylem and cortex were faint yellow.

Fungal Aluminum: Al was absent or questionably present in very small amounts in the mantle cells in the spring 1999 of the unlimed roots. Al was present in limed probes in spring 1999 (0-10 cm depth) (Figure 12-7B, C, D) and fall 2000 (30-40 cm depth).

Root Aluminum: There were seasonal differences in Al content. When Al was absent in the mantle, it was strongly present in the cortex but weakly in the xylem (spring 1999) and when Al was present in the mantle it was reduced in the cortex and xylem (fall 2000).

Summary: *Cortinarius bolaris* mycorrhizae were rarely found. The unlimed samples showed more autofluorescence variability than the limed probes. When Al was retained by the mantle, less was evident in the cortex and xylem. The limed probes had the strongest Al content overall.

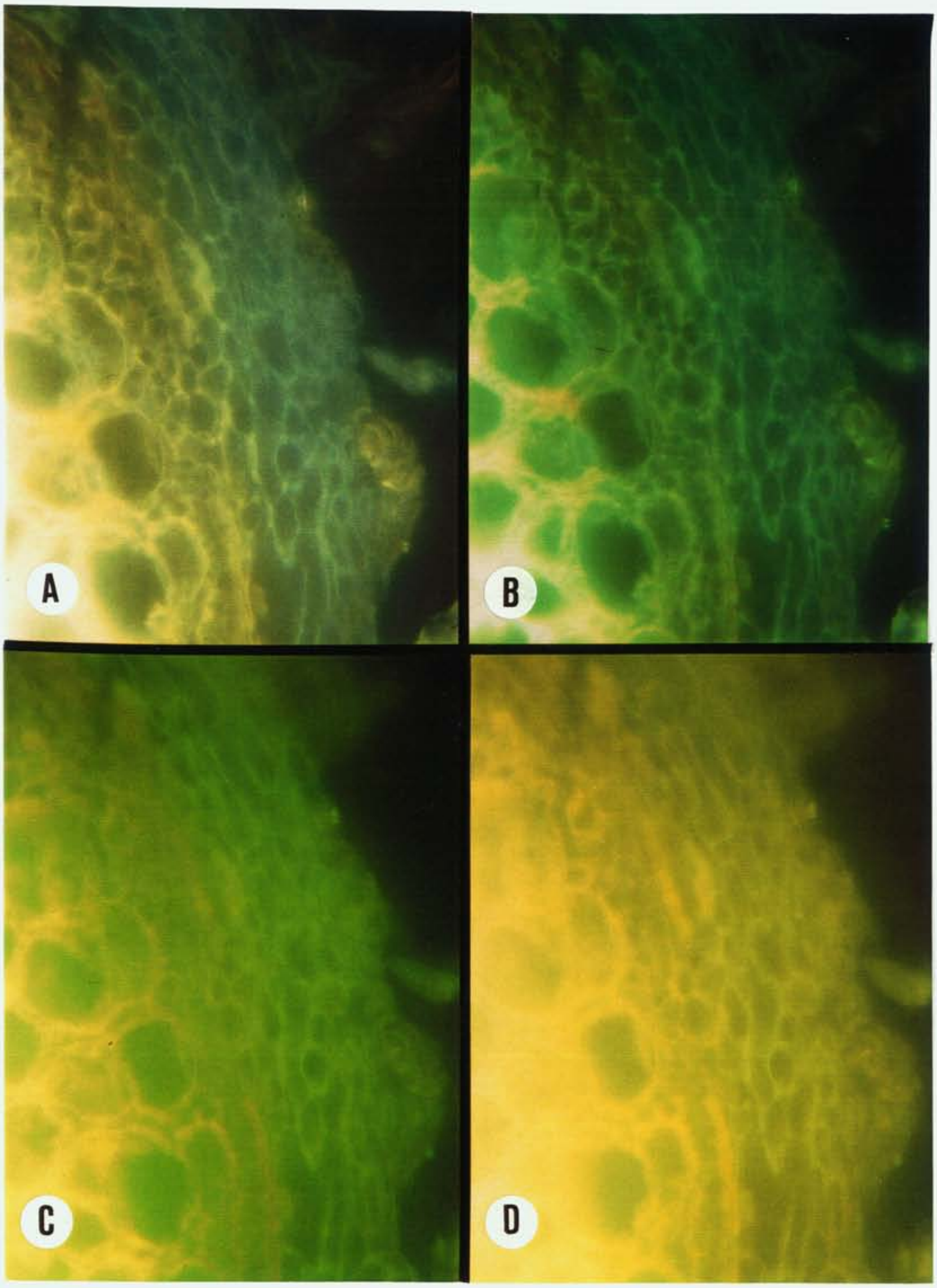
Figure 12-7A: *Cortinarius bolaris* autofluorescence < 1 mm from tip. The natural fluorescence is enhanced here to show better contrast between the blue of the outer mantle and the green of the inner mantle and orange of the Hartig net. With a clear filter all the colors were less intense. Probe 6KA from limed soil at 0-10 cm depth in spring 1999. Cx. 1000x. Photo 3-2, blue filter, 60 second exposure.

Figure 12-7A: *Cortinarius bolaris* with Morin < 1 mm from tip, 1 minute. The Morin dye front is seen moving over the section from right to left. The mantle outer and inner regions have become duller green while the left lower corner where the Hartig net is seen is still bright yellow. Probe 6KA from limed soil at 0-10 cm depth in spring 1999. Cx. 1000x. Photo 3-3, green filter, 40 second exposure, 1 minute after treatment.

Figure 12-7A: *Cortinarius bolaris* with Morin < 1 mm from tip, 5 minutes. The Morin front has moved across the whole section and the orange-yellow color indicative of aluminum presence when using a green filter combination is evident. Probe 6KA from limed soil at 0-10 cm depth in spring 1999. Cx. 1000x. Photo 3-3, green filter, 60 second exposure, 5 minutes after treatment.

Figure 12-7A: *Cortinarius bolaris* autofluorescence < 1 mm from tip, 6+ minutes. The blue filter shows distinct aluminum presence in the mantle and very strong content in the Hartig net cells as well in comparison to Figure 12-7A. Probe 6KA from limed soil at 0-10 cm depth in spring 1999. Cx. 1000x. Photo 3-4, blue filter, 60 second exposure, 6+ minutes after treatment.

12 - 7



Appendix 12-8: Elaphomyces muricatus

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare and limited to mostly to deeper, moist limed soils (Appendices 7-8 and 8A-B3-10).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 53.

Fungal Autofluorescence: In unlimed soil the mantle was variable fluorescing orange or yellow (0-10 cm depth) or blue to bluish-yellow (50-60 cm depth). The Hartig net was blue (0-10 cm depth) or blue green (50-60 cm depth) in unlimed soil. In limed soil the mantle fluoresced pale yellow (0-10 cm depth) to orange-yellow (50-60 cm depth) while the Hartig net was orange (0-10 cm depth) or blue (50-60 cm depth) (Figure 12-8A).

Root Autofluorescence: Typical. In one case the cortex was blue green (50-60 cm depth, unlimed soil) (Figure 12-8A).

Fungal Aluminum: The mantle cells in unlimed soil were mostly Al-free but with specks while the Hartig net contained questionable to minimal amounts of Al. The mantle cells from the limed soil contained large amounts of Al while the Hartig net was mostly Al-free.

Root Aluminum: Roots from 50-60 cm depths contained the most Al in both the unlimed and limed plots. In unlimed probes, the relative concentration of Al was low in the mantle but greater in the cortex and xylem. In limed probes, when Al was greater in the mantle, it was reduced in the cortex and negligible or absent in the xylem.

Summary: There seems to be two opposing trends occurring in *Elaphomyces muricatus* mycorrhizae depending upon the presence of extra lime in the soil. Where lime was present, the mycorrhiza sequestered Al, reducing its total translocation while in the unlimed soil the mycorrhiza did not accumulate Al but allows it to pass increasing the accumulation in the xylem. Assuming that liming increases nutrient uptake, this species may act as a filter, preventing excess Al uptake.

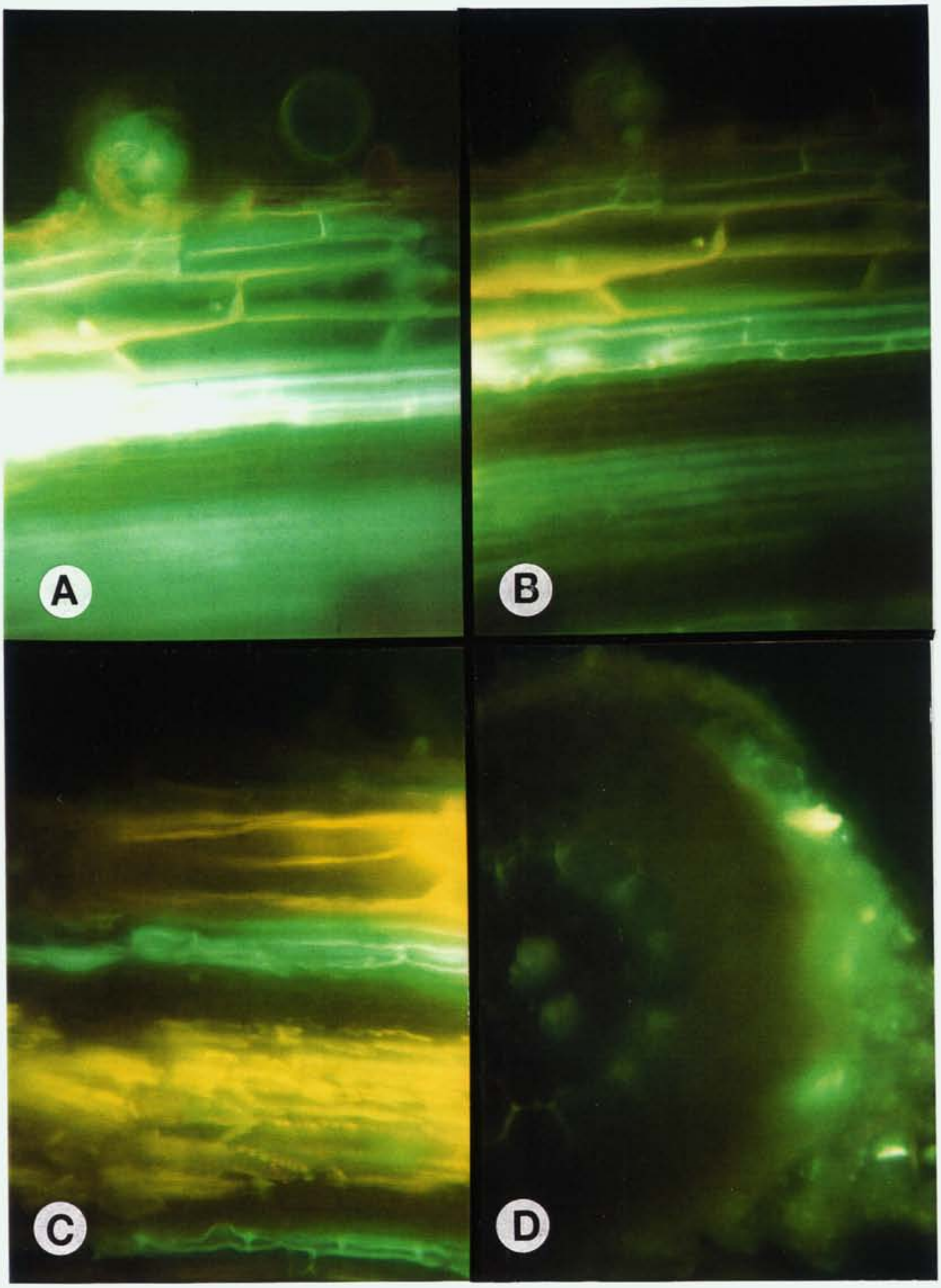
Figure 12-8A: *Elaphomyces muricatus* autofluorescence > 5 mm from tip. The mantle is one layer thick with dull orange fluorescence with a small hyphal emanation visible (top right) and a curled gelatinous mass (top left). Going down through the root layers, the elongated cortical cells are yellow to bright green-blue while the endodermis is brilliant white-blue and the xylem is blue. Probe 1000K from limed soil at 0-10 cm depth, fall 2000. Lx. 400x. Photo 22-21, clear filter, 45 second exposure.

Figure 12-8B: *Elaphomyces muricatus* with Morin > 5 mm from tip. Aluminum is evident only in the elongated cortical cells which are now more intense yellow. Probe 1000K from limed soil at 0-10 cm depth, fall 2000. Lx. 400x. Photo 22-23, clear filter, 8 second exposure, 2 minutes after treatment

Figure 12-8C: *Elaphomyces muricatus* with Morin > 5 mm from tip. The Morin dye has now penetrated to the xylem and an intense reaction show abundant aluminum present in both the cortex and xylem but nowhere else. Probe 1000K from limed soil at 0-10 cm depth, fall 2000. Lx. 400x. Photo 22-24, clear filter, 15 second exposure, 5 minutes after treatment

Figure 12-8D: *Elaphomyces muricatus* with Morin < 1 mm from tip. Despite long exposure to Morin there is minimal response indicating negligible Al content. Probe 800N from unlimed soil at 0-10 cm depth in fall 2000. Cx. 400x. Photo 33-28, clear filter, 30 second exposure, 10 minutes after treatment.

12-8



Appendix 12-9: Fagirhiza arachnoidea

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare to uncommon. Found mostly at 0-10 cm depth in both limed and unlimed forest in moist fall soil (Appendices 7-9 and 8A-B3-11).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 69. This uncommon ectomycorrhiza was recognized by the dense white web of emanating hyphae over the coralloid ectomycorrhizal system.

Fungal Autofluorescence: The mantle, and Hartig net cells in both the limed an unlimed probes at 0-10 cm depth fluoresced very faint to faint green while the hyphae were brighter green (No photographs).

Root Autofluorescence: The xylem, pericycle and endodermis were bright blue while the cortex was pale blue and the phloem cells were non-fluorescent in all the mycorrhizae.

Fungal Aluminum: While the mantle and Hartig net cells fluoresced slightly brighter green to greenish blue in the presence of Morin, this was not taken to be a positive sign for the presence of aluminum. The hyphae did not change color (No photographs).

Root Aluminum: In both the limed and unlimed probes at 0-10 cm depth, xylem cell walls consistently contained aluminum but the cortical cells were variable with more aluminum present in the outer zones. No aluminum was evident elsewhere in the root or mantle areas.

Summary: In *Fagirhiza arachnoidea*, both the limed and unlimed mycorrhizae behaved in the same fashion. The mycorrhiza did not contain aluminum and apparently did not greatly inhibit movement of the ion into the root. The variability of the aluminum in the cortex and the presence of the fluorescent green chemical complexes in the mycorrhizal walls may be associated with a modest filtering capacity.

Appendix 12-10: Fagirhiza cystidiophora

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Uncommon. but found both in limed and unlimed soils at 0-10 cm depth in moist fall soil (Appendices 7-10 and 8A-B3-12).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 15.

Fungal Autofluorescence: At 0-10 cm depth, in unlimed soil, the mantle and hyphae appeared very faint orange while the cystidia were bright orange and the cells in the region of the Hartig net were faint blue green. Mycorrhizal from limed soil were similar except that the hyphae were faint yellow. Further from the tip fewer cystidia were present and the mantle tended to become dull yellow to green (Figure 12-10A).

Root Autofluorescence: Typical: The xylem, pericycle and endodermis were bright blue, the phloem was non-fluorescent and the cortex duller blue to blue green (Figure 12-10A).

Fungal Aluminum: In unlimed soil Hartig net had the most Al, while the mantle and hyphae contained negligible amounts. In limed soil, the mantle and hyphal cells contained the most Al, while the Hartig net cells a reduced Al content. The cystidia were Al-free in both unlimed and limed probes.

Root Aluminum: In both unlimed and limed soil, the xylem and cortex contained Al but that the cortical cells were more variable in their Al content in the limed probes.

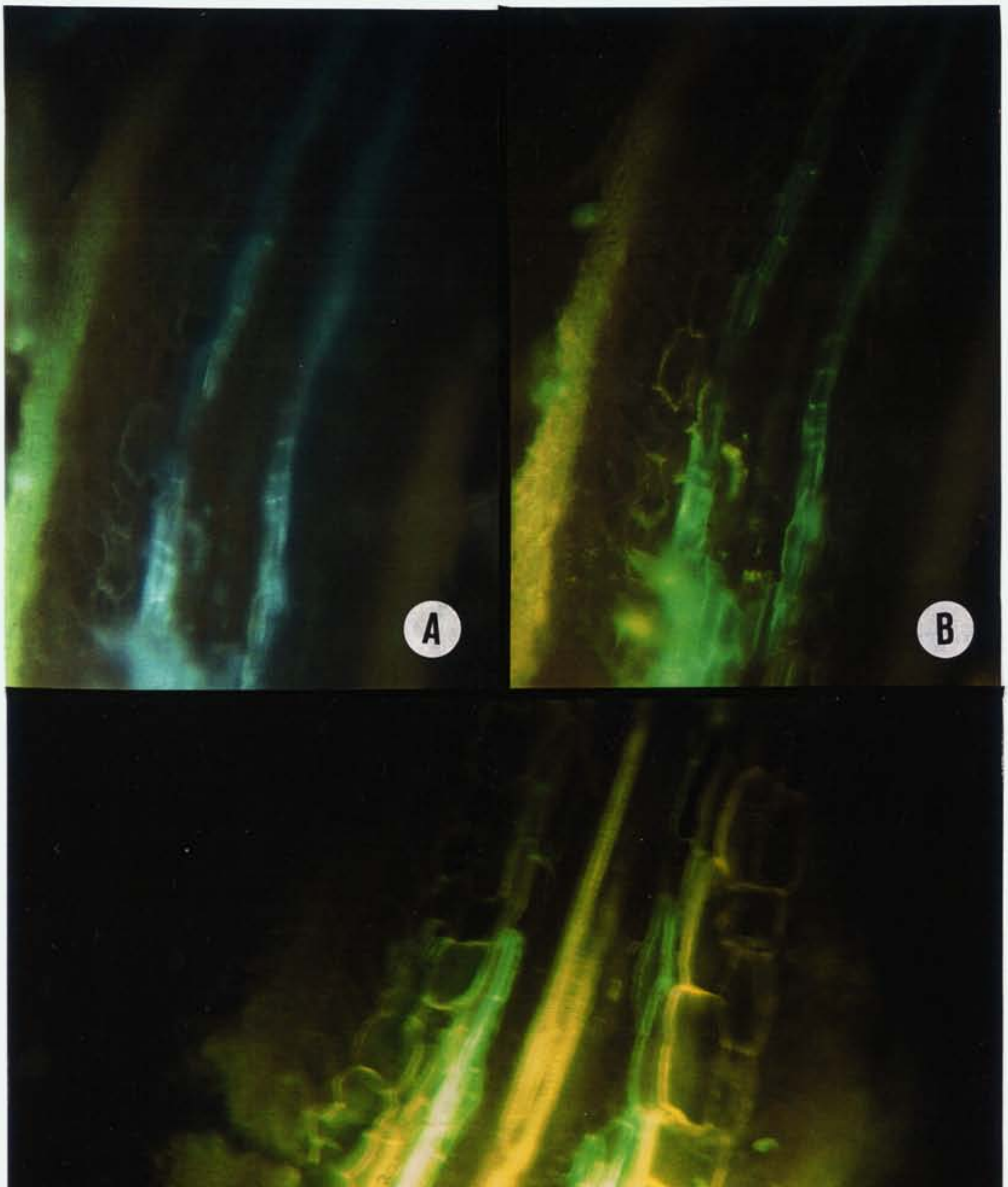
Summary: In *Fagirhiza cystidiophora* from unlimed soil there was less Al evident in the outer mantle but more present internally. Conversely in limed soil when there was an elevated Al presence in the mantle there was less evident in the cortex. It was not possible to determine visually which isolates had the most aluminum.

Figure 12-10A: ***Fagirhiza cystidiophora*** **autofluorescence > 5 mm from tip.** The mantle is a dull to bright green. The cortical and xylem fluoresce poorly while the endodermal and pericycle layers are bright blue. Probe 1400N from unlimed soil at 0-10 cm depth, fall 2000. Lx. 250x. Photo 32-17, clear filter, 90 second exposure.

Figure 12-10B: ***Fagirhiza cystidiophora*** **with Morin > 5 mm from tip.** The mantle contains aluminum in regions that previously fluoresced bright green. The cortical cells show minimal Al content. Probe 1400N from unlimed soil at 0-10 cm depth, fall 2000. Lx. 250x. Photo 32-19, clear filter, 90 second exposure, 5 minutes after treatment.

Figure 12-10C: ***Fagirhiza cystidiophora*** **with Morin > 5 mm from tip.** The mantle here contains less Aluminum, but conversely, the cortical and xylem cells have intense Aluminum content. This is the same mycorrhizal species as in Figure 12-10B, but from tree 1100 which subsequently died (winter 2002). A change in mycorrhizal function may be an early indicator of fatal stress. Probe 1100N from unlimed soil at 0-10 cm depth, fall 2000. Lx. 250x. Photo 16-19, clear filter, 90 second exposure, 5 minutes after treatment.

12 -10



Appendix 12-11: Fagirhiza fusca

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare (unlimed) to common (limed), prevalent in moist soil at 0-10 cm (limed) or 30-40 cm depth (unlimed) in spring (Appendices 7-11 and 8A-B3-13).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 56. The large monopodal to pinnate ectomycorrhizal systems were most easily distinguished by the fine cottony envelope of emanating brown to mauve hyphae (Figure 12-11A).

Fungal Autofluorescence: In most cases the mycorrhizal mantle and hyphae were non-fluorescent (Figure 12-11B) except for a few very young samples from unlimed soil (spring 1999) which had blue specks. The Hartig net was often blue or very faintly orange. There was no discernible pattern to the color variations.

Root Autofluorescence: The xylem was blue while the pericycle and endodermis were bright blue to blue green. The phloem was non-fluorescent except for one sample (spring 1999, 30-40 cm depth) where it was very faint green at < 1 mm from the tip. In unlimed soil, the cortex was consistently but in limed soil the cortex was blue to bluish yellow to yellowish blue with the yellow tinges more evident in drier soil (Figure 12-11B)

Fungal Aluminum: The mycorrhiza from the unlimed soil were Al-free with the exception one the probe (spring 1999, 30-40 cm depth) which contained al specks in the mantle and hyphae but not the Hartig net. The mycorrhizae from the limed soil were Al-free in the mantle and hyphal cell walls but had variable amounts of Al in the Hartig net.

Root Aluminum: In the unlimed probes, Al was absent or occasionally irregularly present in the xylem and cortex. In the limed probes, Al was present in the xylem, strongly present in the cortex and variably present in the Hartig net region. In sections, the limed roots were much more irregular in cortical structure.

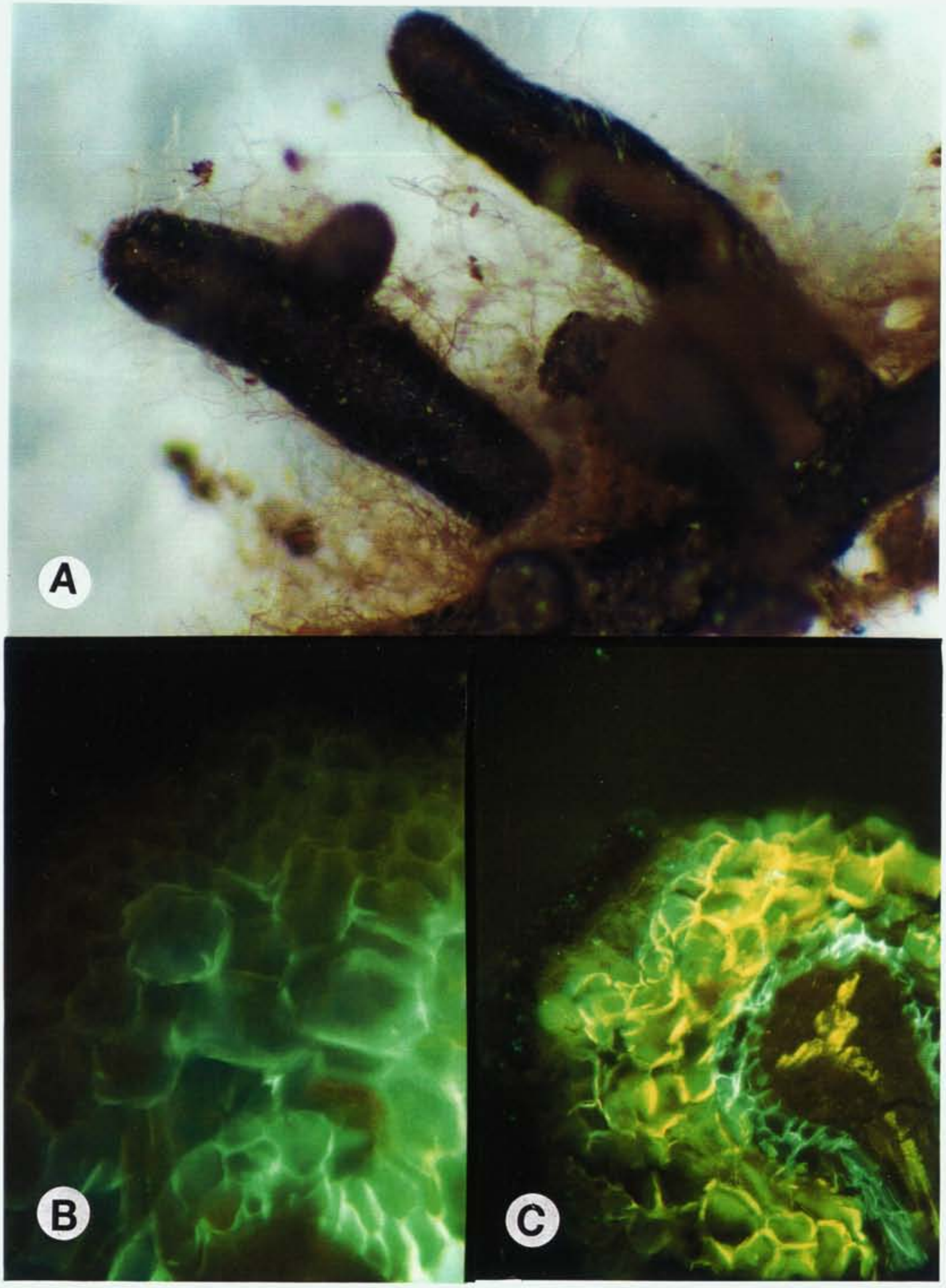
Summary: *Fagirhiza fusca* from the limed soil contained more Al (especially in the Hartig net) than those from the unlimed soil.. The poorer storage of toxic Al ions in the unlimed soil may protect the unlimed roots from damage.

Figure 12-11A: *Fagirhiza fusca* gross morphology. Older dark mycorrhizae with one new small lighter branched tip and monopodal ectomycorrhizal system with a fine cottony envelope of emanating hyphae with few ramifications. Probe 200K from limed soil at 0-10 cm depth in spring 2000. 250x. Photo 7-38.

Figure 12-11B: *Fagirhiza fusca* autofluorescence < 1 mm from tip. The mantle is non-fluorescent (top) and the Hartig net is barely visible while the irregular cortical cells are bright blue-green. Probe 900K from limed soil at 0-10 cm depth in fall 2000. Cx. 400x. Photo 26-31, clear filter, 30 second exposure.

Figure 12-11C: *Fagirhiza fusca* with Morin < 1 mm from tip. Aluminum is present in the xylem in the central cylinder and in the emanating secondary root (lower right). Al is variable in the cortex (bright yellow areas) and spotty in the mantle (green specks). Probe 900K from limed soil at 0-10 cm depth in fall 2000. Cx. 400x. Photo 27-2, clear filter, 60 second exposure, 11 minutes after treatment.

12-11



Appendix 12-12: Fagirhiza granulosa

Fruiting body Occurrence: According to Agerer (1987-1998) *Russula fella* may be the fruiting body associated with *Fagirhiza granulosa.* A few fruiting bodies of *Russula fella* was found in the unlimed plot only in fall 2000 (Appendix 2C).

Mycorrhizal Occurrence: Common from 0 to 60 cm depth in both limed and unlimed soils but most prevalent at 0-10 cm depth in moist soil, while during dry seasons it tends to be found in deeper horizons (Appendices 7-12 and 8A-B3-16).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 16.(Figure 12-12A, B, C).

Fungal Autofluorescence: In unlimed soil, the mycorrhizal mantles fluoresced faint yellow to faint yellow-green in the spring probes, while fall probes were somewhat more orange in fluorescence varying from non-fluorescence or very faint yellow to yellow green to faint orange to orange, implying a chemical change upon aging or with seasonal change (Figure 12-12D). In the Hartig net area, the fungal cells varied from faint blue to very faint orange-blue (at all depths) to occasionally faint yellow-blue (only at 30-40 cm depth) in the spring; while in the fall they tended to be yellower in tint varying from faint yellow-green to very faint yellow (Figure 12-12D). Interestingly, relative to the mantle cells, if the Hartig net had a yellow tint, the mantle was tinted orange and vica versa. If color complexes are relative to function then it is possible that the mantle and Hartig net reverse roles depending upon the season.

In limed soil, the mantle consistently was yellow-green in fluorescence with only occasional changes to yellow or yellow-orange at > 5 mm from the tip in some fall samples from 0-10 cm depth (Figure 12-12E).. The Hartig net fungal cells were faint orange (outer layer) to bluish-yellow (inner layer) at 0-10 cm depth at every season. At 30-40 cm depth, the net was uniformly very faint yellow in spring to orange, and at 50-60 cm depth the net was very faint yellow in spring to yellow-green, in fall. The orange coloration in the mantle occurs upon seasonal aging at all depths. The samples examined from limed probes were much less variable than those extracted from the unlimed soil.

Root Autofluorescence: The xylem consistently fluoresced blue. The phloem was non-fluorescent. The pericycle and endodermis were bright blue at 0-10 cm depth, blue (limed soil) or blue-green (unlimed soil) at 30-40 cm depth, and blue green (unlimed soil) or blue to yellow-green to green (limed soil) at 50-60 cm depth. Generally the pericycle and endodermis become greener with depth especially in the unlimed samples. In unlimed soil at 0-10 cm depth the cortex was faint blue (spring 2000) and yellow-green (fall 2000). At 30-40 cm depth, the cortex color also became yellower with time varying from faint blue to orange blue (1999) to yellow-blue (spring 2000) to yellow-green (fall 2000). At 50-60 cm depth the seasonal color change was orange-blue (spring 1999) to faint blue (spring 2000) to faint yellow (fall 2000) in the unlimed probes (Figure 12-12D).

In limed soil at 0-10 cm depth the cortex was very faint yellow-green (1999) to bluish-yellow (2000) and at 30-40 cm depth it was blue (spring 2000) and faint yellow (fall 2000) and at 50-60 cm depth it was yellow-blue (Figure 12-12E). The fluorescence was more consistent than in the unlimed probes and the tendency to yellowing was most pronounced only at 30-40 cm depth and not at all depths as in the unlimed probes.

Fungal Aluminum: In unlimed soil the aluminum content of the mantle was quite variable tending to be absent or questionably present in spring and occasionally present in fall especially as green to yellow-green specks. In the Hartig net region, at 0-10 cm depth, Al was generally present in the spring but absent in the fall; at 30-40 cm depth, the reverse trend appeared where Al was absent in the spring but present in the fall (perhaps a late season leaching phenomena); and at 50-60 cm depth Al tended to be absent in the dry 1999 spring season but faintly present in the wet 2000 spring season and questionably present in the wet fall. There were definite differences in Al accumulation relative to depth with the most accumulations occurring at 30-40 cm (Figure 12-12D)In limed soil, the mantle Al was evident in the fall samples often as green specks, but mostly absent in the spring . The Hartig net area, Al was absent at 0-10 cm depth (Figure 12-12F), faint to absent at 30-40 cm but questionably to strongly present at 50-60 cm depth.

Root Aluminum: In unlimed soil, the root cortex often had more Al present in the spring than in the fall samples, at all depths. Interestingly, if Al was present in the fungal cells it was absent or reduced in the cortex and vica versa, if it was absent in the fungal cells, it was more strongly present in the cortex. However, if Al was very strongly present in the fungal cells, it was also very strongly present in the cortex and xylem (Figure 12-12D). Except for one sample (spring 2000), Al was absent from the endodermis and pericycle. Al was absent from the phloem except at 30-40 cm depth where it was weakly present. Al was present in the xylem although it was occasionally absent at < 1 mm from the root tips.

In limed soil, in the root cortex, Al was strongly present in the spring but in the fall samples, while Al was strongly evident from 0-10 (Figure 12-12F) and 50-60 cm depth it was absent at 30-40 cm depth. Al was absent from the endodemal and pericycle cells, but occasionally present in the phloem at 30-40 cm depth and at 50-60 cm depth especially in the spring. The xylem aluminum was more common than in the unlimed probes but in a similar fashion, Al was occasionally absent at <1 mm from the root tips.

Summary: *Fagirhiza granulosa* seems to undergo seasonal chemical changes in the walls evidenced by trends to increased orange or green autofluorescent pigmentation with aging. In the limed samples the mantle cells tended to be greener, while the net cells drifted in the orange range and in the unlimed samples, the fungal mantle and Hartig cells both favored the greener tones at shallower soil depths (0-10 and 30-40 cm). Changes in aluminum accumulation seemed to be affected by the chemical changes in fungal wall make up but no consistent pattern could be discerned in this highly dynamic system.

Generally if aluminum was sequestered by the mycorrhiza, less was evident in the cortex but the responses fluctuated. Regardless of whether the mycorrhiza were from limed or unlimed soils, the aluminum accumulations were variable but generally greater accumulations occurred at increased depths.

Figure 12-12A: *Fagirhiza granulosa* gross morphology. Monopodal short-branched mycorrhizal system with warty mantle surface and some axial debris. Probe 500N from unlimed soil at 0-10 cm depth in spring 2000. 200x. Photo 5-6.

Figure 12-12B: *Fagirhiza granulosa* papillae. Mantle detail of pseudoparenchymatous cells with protruding papillae with clear contents. Probe 1K from limed soil at 0-5 cm depth in spring 1999. Cx. 1000x. Photo 7-2, white light, 15 second exposure.

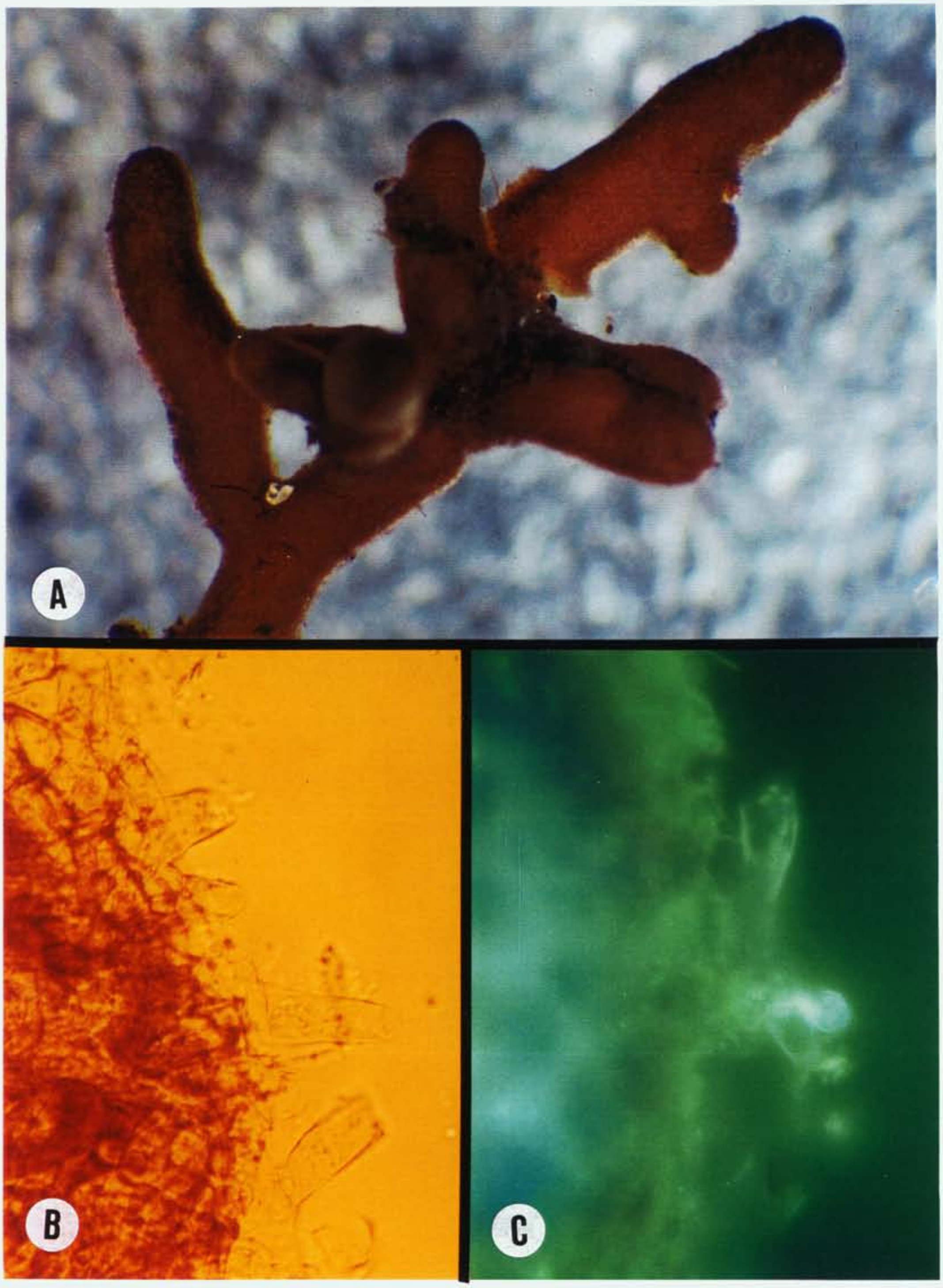
Figure 12-12C: *Fagirhiza granulosa* papillae autofluorescence. Mantle detail of protruding papillae autofluorescing green in the presence of Morin (no Aluminum). Cortex was blue. Probe 11K from limed soil at 0-5 cm depth in spring 1999. Cx. 1000x. Photo 7-2, green filter for improved contrast, 15 second exposure, 5 minutes after treatment.

Figure 12-12D: *Fagirhiza granulosa* with Morin < 1 mm from tip. Mantle is non-fluorescent to autofluorescing very dull orange to green. Aluminum is present only in some Hartig net cells (lower left) and the adjacent cortical cells. Probe 500N from unlimed soil at 0-10 cm depth in spring 2000. Cx. 1000x. Photo 38-35, clear filter, 60 second exposure, 2 minutes after treatment.

Figure 12-12E: *Fagirhiza granulosa* autofluorescence > 5 mm from tip. Mantle is very thick here with an outer region which fluoresces dull to bright green-yellow and an inner area of collapses Hartig net which is dull orange. The cortical cell layers are dull blue while the pericycle ring and xylem is bright blue. Probe 1100N from unlimed soil at 0-10 cm depth in fall 2000. Cx. 250x. Photo 16-22, clear filter, 45 second exposure.

Figure 12-12F: *Fagirhiza granulosa* with Morin > 5 mm from tip. Mantle and Hartig net are Al-free but the cortical cells show strong Al content. The xylem is inconsistently yellow in patches. Probe 1100N from unlimed soil at 0-10 cm depth in fall 2000. Cx. 250x. Photo 16-23, clear filter, 45 second exposure, 5 minutes after treatment.

12·12



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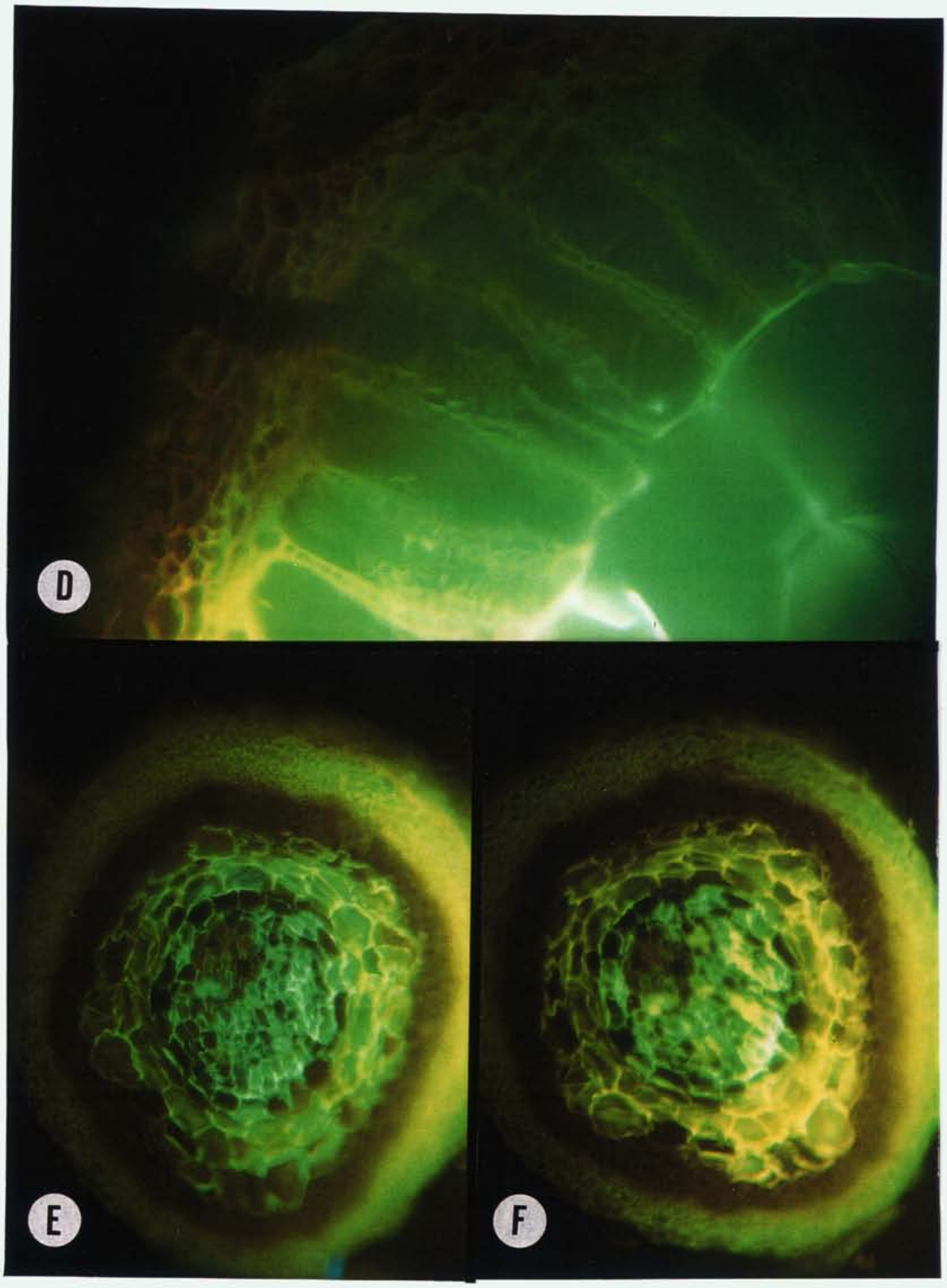


Appendix 12-13: Fagirhiza setifera

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Mycorrhizae were found in both limed and unlimed soils (Appendices 7-13 and 8A-B3-16). In the spring of 1999, this species was most common at 30-40 cm. In the very dry fall 1999 they almost completely disappeared from all horizons. In the spring of 2000 they were found at every depth in unlimed soil, but only at 30-40 cm and deeper in the limed soil. In the fall of 2000 they reappeared in the 0-10 horizon but disappeared from the 50-60 cm depths. When the soil is dry, this species is capable of existing at lower soil horizons and when the moisture returns, they can return to the upper soil. Their "disappearance" during very dry seasons may be an illusion. It is likely that unrecognized vegetative hyphae may have survived in the desiccated soil.

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 55.

Fungal Autofluorescence: Emanating hyphae and outer mantle cells were normally non-fluorescent but in unlimed soil, a few were occasionally yellowish (Figures 12-13B, 12-13C). In unlimed soil, the Hartig net cells (fungal cells in proximity to the epidermal and hypodermal root cells) appeared faint blue to faint yellow in the spring but they were very faint blue in the fall. In limed soil, the Hartig net cells were faint blue to bluish-yellow in spring and faint orange in fall.

Root Autofluorescence: The xylem, pericycle and endodermis were usually bright blue while the root cortex was usually faint blue with some occasional yellowish-blue tints in deeper soil. The phloem was non-fluorescent or faint orange in older regions (Figures 12-13B, 12-13C).

Fungal Aluminum: In unlimed soil, Aluminum was present in both the emanating hyphae and the mantle cells in the spring of 1999, especially in locations further from the apex. When the mycorrhizae reappeared in spring 2000 at 30-40 cm and 50-60 cm depths, there was no evidence of aluminum but the following fall aluminum was again present in the tips extracted from 0-10 and 30-40 cm depths. Aluminum was faintly present in the Hartig net area in most samples regardless of season appearing as specks and wall deposits with slightly more present as depth increased. In limed soil, no aluminum was found in the hyphae or outer mantle cells, but at 30-40 cm depth some external green specks were present. In the Hartig net areas, aluminum was faintly present in the spring samples but absent or less evident in the fall samples and as depth increased (Figure 12-13D). It is possible that temporal accumulation of aluminum in the unlimed probes may have adversely affected mycorrhizal survival in conjunction with the fall 1999 drought, however, during the same time periods next to no aluminum was present in the limed probes and they also disappeared, so the likelihood is that the soil desiccation was the primary factor in the loss of this mycorrhizal species.

Root Aluminum: In unlimed soil, Aluminum was weak (30-40 cm) to strongly (0-10, 50-60 cm depth) present in the xylem. Al was very weakly present in the phloem, pericycle and endodermis walls at 50-60 cm depth. The cortical cells were variable to strong in the intensity of aluminum deposits with a green tint present occasionally as depth increased. In limed soil, Aluminum was variable (0-10, 50-60 cm depth) (Figure 12-13D) to more intensely (30-40 cm) present, especially near the apex (Figure 12-13A). Specks of aluminum were present in the phloem at 0-10 cm depth and in the pericycle and endodermal areas at 30-40 cm depth. As depth increased, the abundance of aluminum in the cortical cell walls tended to decrease, however at 50-60 cm depth aluminum accumulations next to the endodermal barrier walls was greater than elsewhere in the cortex. An increase in green tint was also apparent as depth increased.

Summary: Interestingly, the patterns of aluminum deposits in *Fagirhiza setifera* mycorrhiza from unlimed and limed soils were often reverse mirror images of each other. If the aluminum was strongly present in one group at a certain depth and location, in the other it was weakly present to absent. Samples from the limed soil tended to have less apparent Al present than those from unlimed soil implying a somewhat improved exclusion system.

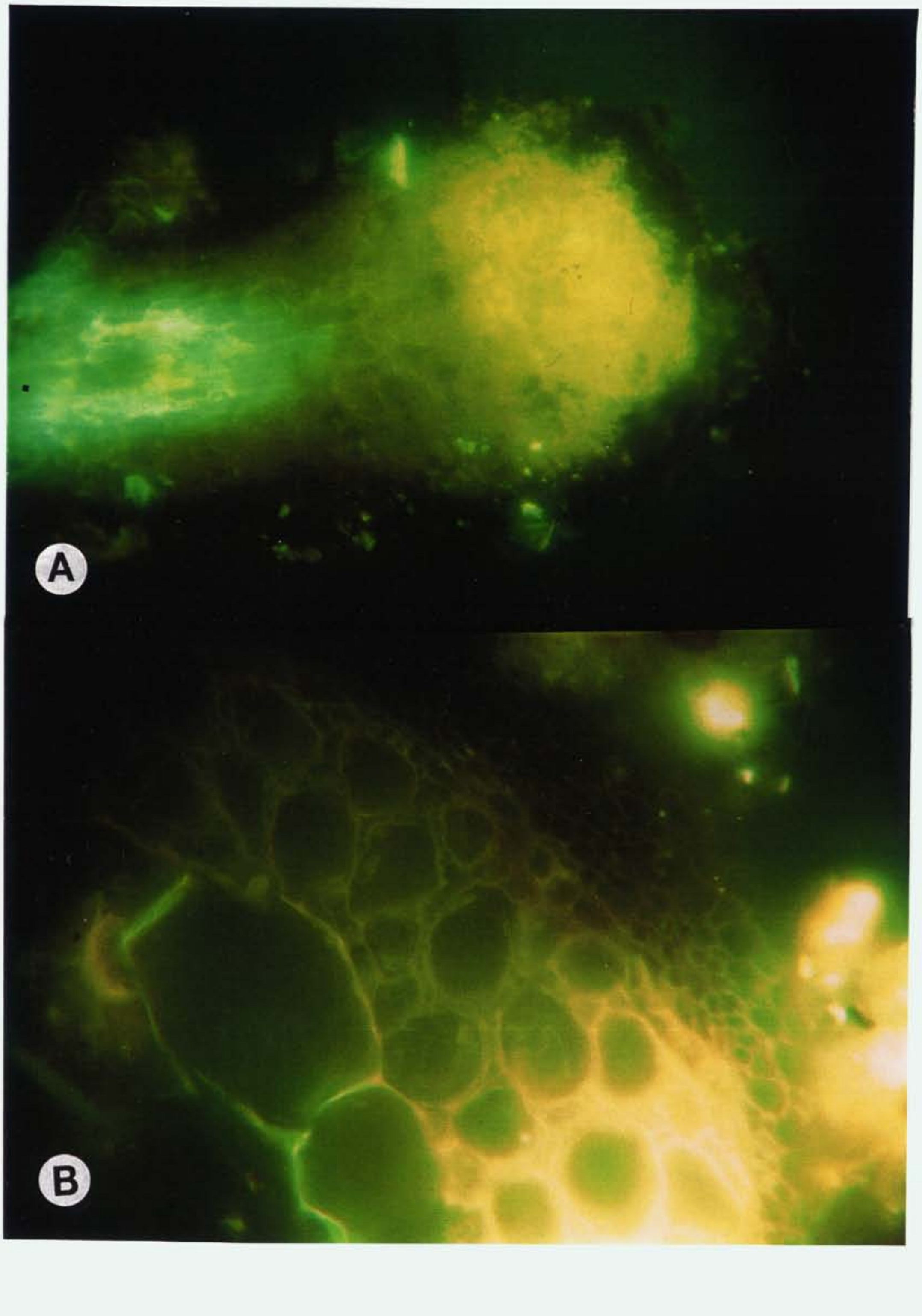
Figure 12-13A: *Fagirhiza setifera* tip with Morin. The rounded tip of the ectomycorrhizal system showed intense aluminum accumulation in the meristem (bright yellow) and many spots of aluminum accumulation (yellow-green specks) in the region of the dark non-fluorescent mantle. The spots seemed most intense in areas of disrupted mantle in the growing tip rather than within the mantle walls proper. Probe 1KA from limed soil at 30-40 cm depth in spring 1999. Lx. 400x. Photo 9-1, green filter, 45 second exposure, 5 minutes after Morin treatment.

Figure 12-13B: *Fagirhiza setifera* autofluorescence > 5 mm from tip. The mantle was primarily non-fluorescent except in areas such as shown here (bottom right) where there was physical damage. Physical damage was more prevalent in the probes from deep soil. The penetration of hyphae between the root cells is evident up to the large cortical cells. (Left). Probe 1KA from limed soil at 50-60 cm depth, spring 1999. Cx. 1000x. Photo 10-35, green filter, 90 second exposure.

Figure 12-13C: *Fagirhiza setifera* autofluorescence < 1 mm from tip. The mantle is non-fluorescent and so only barely visible. On the left, a small region of the Hartig net is faintly visible with dull orange fluorescence. The root cells are all brightly blue in fluorescence except for the phloem which is dull orange. Probe 1K from limed soil at 0-10 cm depth in spring 1999. Cx. 400x. Photo 6-27, clear filter, 10 second exposure.

Figure 12-13D: *Fagirhiza setifera* with Morin < 1 mm from tip. The mantle is Al-free, while a small segment of the Hartig net is more visible indicating minimal Al content. The cortical cells (especially on the left) and the xylem are strongly fluorescent indicating abundant Al. The axial barrier to aluminum penetration into the secondary root is visible to the left of the emergence point from the stele. Probe 1K from limed soil at 0-5 cm depth, spring 1999. Cx. 400x. Photo 6-28, clear filter, 10 second exposure, 5 minutes after treatment.

12·13



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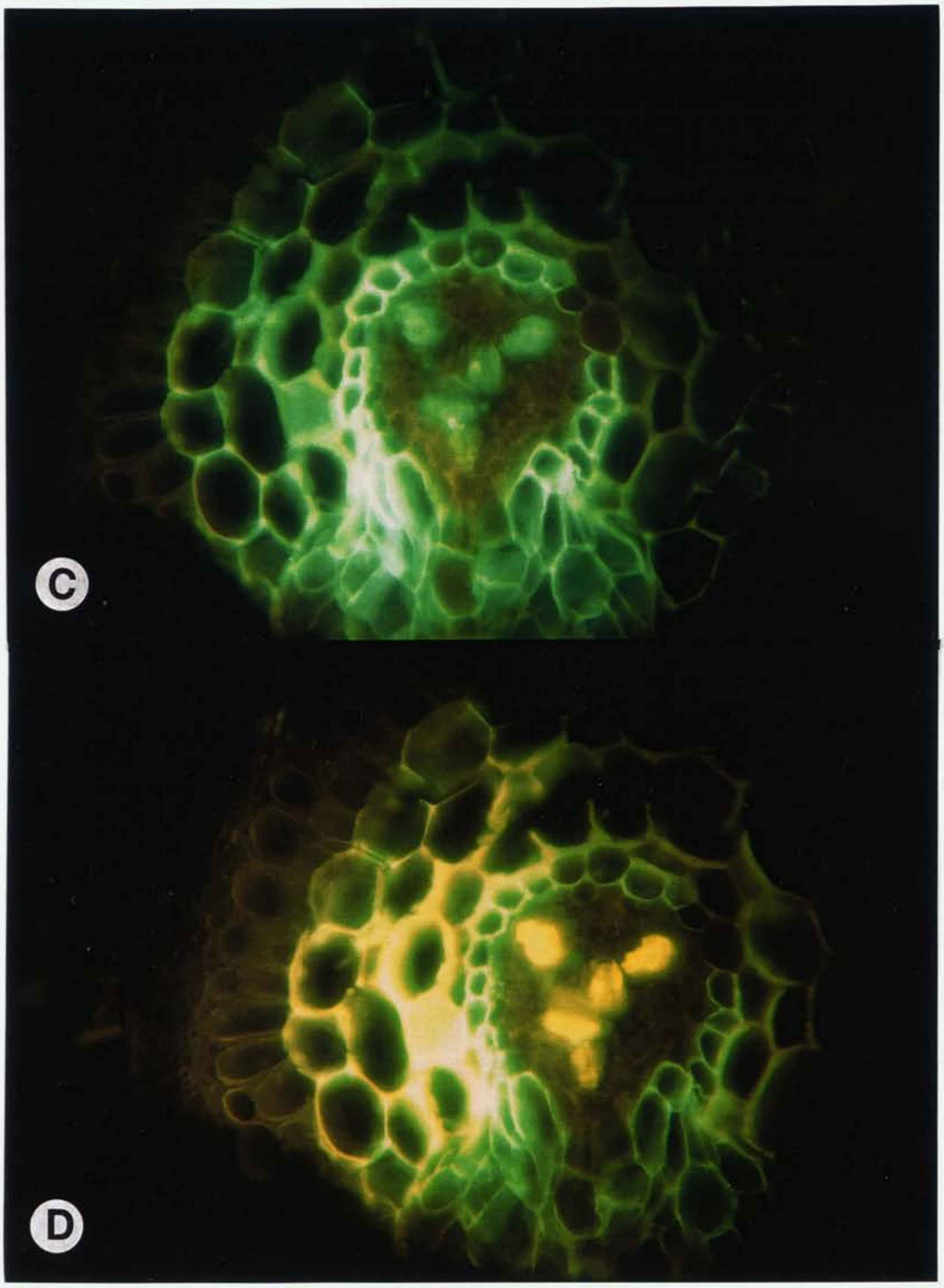


Appendix 12-14: Fagirhiza spinulosa

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Fagirhiza spinulosa* was present at 0-10 cm, infrequent at 30-40 cm and present (unlimed) or absent (limed) from 50-60 cm in spring 1999 and fall 2000, and conspicuously absent in the intervening dry fall and following spring implying a long recovery period from desiccation stress. (Appendices 7-14 and 8A-B3-18).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 54.

Fungal Autofluorescence: The mantle and emanating hyphal cells are non-fluorescent while the Hartig net cells invading the root epidermal and hypodermal interstitial regions were non-fluorescent to faint orange except for the tiny mycorrhizae found in limed soil at 30-40 cm depth which were bluish (non-fluorescent with a masking glow from the adjacent root cells). In limed soil samples, occasionally, the fungal cells were non-fluorescent but occasionally autofluoresced faintly yellow (Figure 12-14A).

Root Autofluorescence: In all the roots examined, the xylem, pericycle, endodermis autofluoresced bright blue while the cortex was faint blue. The hypodermis and endodermis fluoresced faint orange except at 30-40 cm depth in limed soil where the immature cells were blue. The orange coloration of the epidermal and hypodermal cells in the region of the fungal Hartig net may be an invasion response since it was very typical for this species. The phloem was non-fluorescent (Figure 12-14B). In one sample where the tip had died, all the cells including the phloem, but not the xylem, fluoresced faint orange at <1 mm from the tip but at >5 mm from the tip, the living cells fluoresced normally. The orange pigmentation may be a damage or aging response (Figure 12-14C).

Fungal Aluminum: In the unlimed samples no Al was found in the emanating hyphae or outer mantle cells. The Hartig net cells were primarily also free of aluminum, except for one sample from 0-10 cm depth in fall 2000 which had a strong aluminum presence but only in the inner most less developed regions of the Hartig net. (The adjacent root cortical cells had fainter evidence of aluminum). In the limed soil, the emanating hyphae were aluminum free but at 0-10 cm depth, the outer mantle cells occasionally contained aluminum but the Hartig net remained Al-free. At 30-40 cm depth some Al was present in the inner Hartig net near the hypodermal/cortical cells in the tiny specimens.

Root Aluminum: In unlimed soil, the xylem was variable in its aluminum content being mostly free of Al at 30-40 cm depth and with questionable to small amounts present at 0-10 cm with seemingly less Al present in the fall than the spring. The phloem had specks of aluminum at 30-40 cm depth. The cortex tended to have more Al present in the fall than the spring. The remaining cells were Al-free. In non-mycorrhizal root areas aluminum was present in the xylem and rarely in the cortex.

In the limed soil, the xylem was very variable in its aluminum content at 0-10 cm, but at 30-40 cm depth Al was strongly present. The cortical cells were also very variable in their content. If the aluminum concentration was low in the young mantle, then it was high in the cortex, and was correspondingly low in the xylem. Likewise, if the aluminum content of the older outer mantle was high, then the cortical complement was low but the xylem complement was higher. Occasionally roots and their fungal partners were totally Al-free.

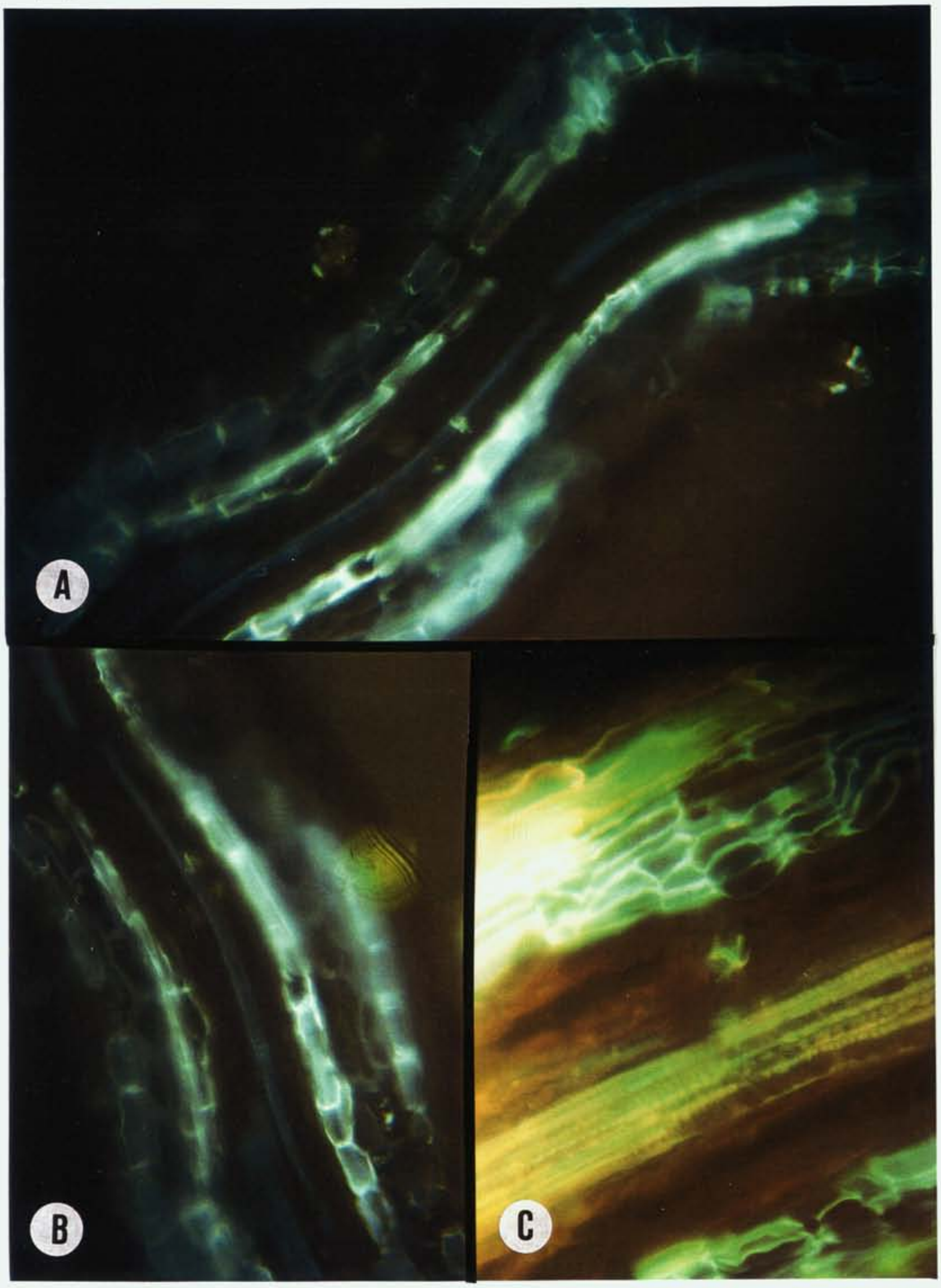
Summary: Some samples from both test areas were totally Al-free. *Fagirhiza spinulosa* seemed most able to prevent Al sequestration in the fungal cells and limit translocation to the xylem in unlimed soil . In limed soil more irregular sequestration and translocation was evident. In the limed soil, translocation of aluminum was a complex phenomena. Where aluminum was present in the mantle, it was less evident in the cortex, but more evident in the xylem; and where Al was absent in the mantle, it was more evident in the cortex but less evident in the xylem. The active fungal barrier seemed to have been compromised by liming especially at 30-40 cm depth.

Figure 12-14A: *Fagirhiza spinulosa* autofluorescence > 5 mm from tip. The fungal mantle, Hartig net and phloem are non-fluorescent while the remaining root cells are visible and fluoresce blue. Probe 1000K from limed soil at 0-10 cm depth in fall 2000. Lx. 400x. Photo 32-6, clear filter, 60 second exposure.

Figure 12-14B: *Fagirhiza spinulosa* with Morin > 5 mm from tip. The root in the area of the fungal mantle was aluminum free. A floating piece of debris fluoresces yellow near the mantle indicating the Morin dye was functional. Probe 1000K from limed soil at 0-10 cm depth in fall 2000. Lx. 400x. Photo 32-9, clear filter, 60 second exposure, 5 minutes after treatment.

Figure 12-14C: *Fagirhiza spinulosa* with Morin beyond the mantle region. The non-mycorrhizal main root in an area from which the Al-free *Fagirhiza spinulosa* tips emerge indicates aluminum content, most likely arising from Al uptake from some other location along the root axis. The older root area shows some aluminum in the outer cortical cells near the collapsed epidermal region with a very thin, incomplete non-fluorescent layer of *Fagirhiza spinulosa* hyphae (Top), while the xylem is clearly seen (bottom) as long Al-rich ringed tubes. The phloem on either side of the xylem autofluoresces dull orange but no Al is present. Probe 1200N from unlimed soil at 30-40 cm depth in fall 2000. Lx. 400x. Photo 31-39, clear filter, 30 second exposure, 10 minutes after treatment.

12·14



Appendix 12-15: Fagirhiza tubulosa

Fruiting body Occurrence: None

Mycorrhizal Occurrence:. *Fagirhiza tubulosa* was strongly present, at 0-10 cm depth in limed soil in spring 1999 and 2000, and fall 2000 but only moderately present in limed probes in fall 2000. It was rare at other depths. (Appendices 7-5 and 8A-B3-19).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 17. *Fagirhiza tubulosa* was easily identified by its silvery golden-white mantle and long twining, medium brown multi-branched hyphae (Figure 12-15A).

Fungal Autofluorescence: In spring all the fungal cells autofluoresced a medium orange, but in the fall the cells in the Hartig net were faint orange and the mantle cells were very faint bluish-yellow while the hyphae became non-fluorescent. The few poor tips from limed soil had green outer mantles and dull green-orange Hartig nets (Figure 12-15B).

Root Autofluorescence: The root cells fluoresced typically except in the spring when many cells were yellowish. The hypodermal and endodermal cells were medium orange in the spring and very faint orange in the fall, Young spring hyphae may affect the metabolic deposition of chemicals in the root cells but lose that ability upon aging.

Fungal Aluminum: The spring samples lacked Al in the hyphae and mantle regions but Al was present in the Hartig net. The fall samples lacked Al in the emanating hyphae and Hartig net, but Al was occasionally present between the inner and outer mantle layers.

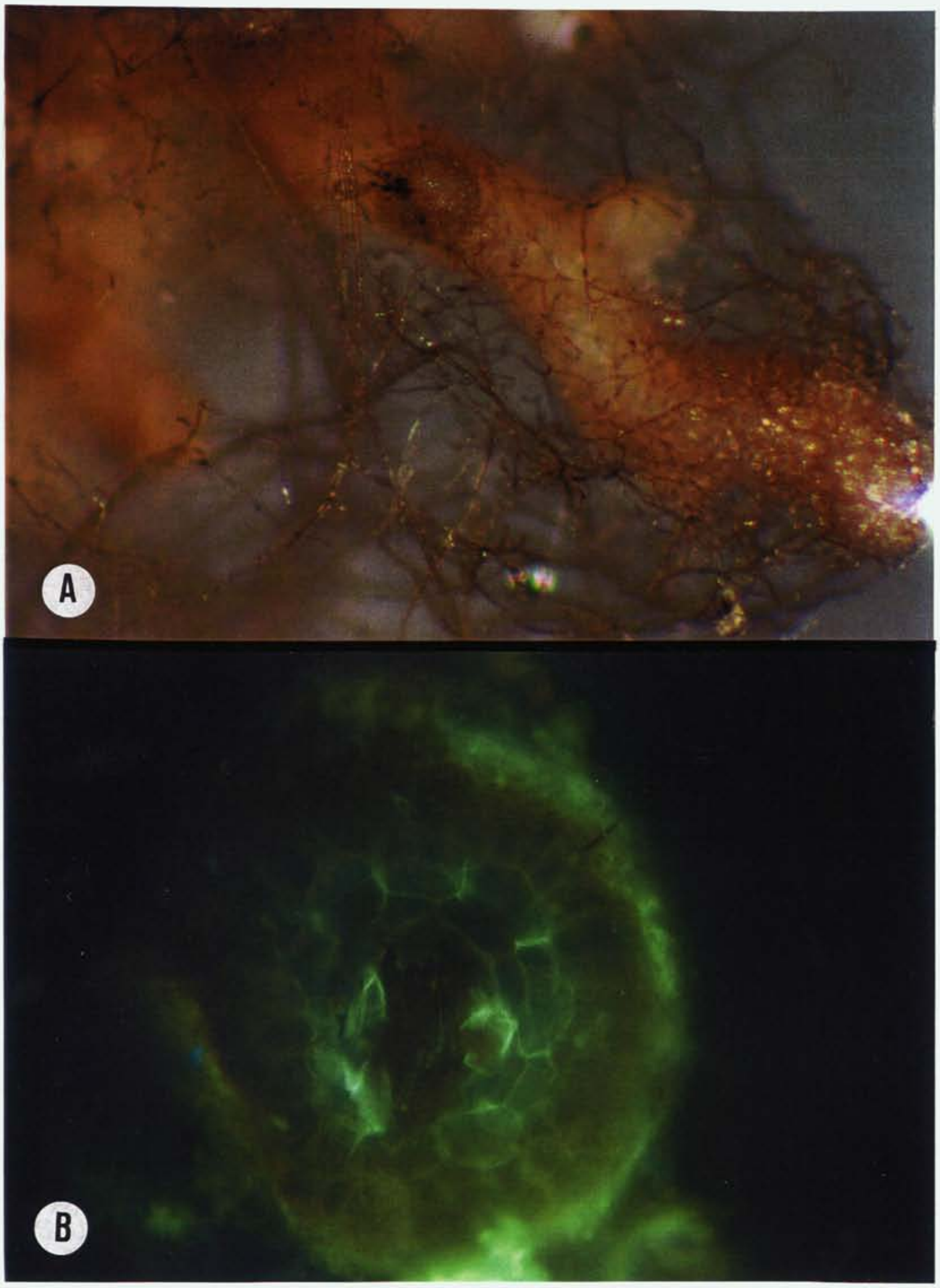
Root Aluminum: In the spring, when Al was present in the Hartig net it was also found in the cortex, outer endodermis and xylem with somewhat less evident in the phloem walls. In the fall, when Al was only occasionally present in the outer mantle, it was also occasionally present in the cortex and weakly present in the xylem and absent elsewhere.

Summary: In *Fagirrhiza tubulosa,* Al was more freely translocated when the mycorrhizal tips were young and more controlled in the older fall tips in well hydrated soils. This species was present only at 0-10 cm depth in unlimed soils and nearly totally absent in limed soils except for a few rare tips.

Figure 12-15A: *Fagirhiza tubulosa* gross morphology. The old mycorrhizae is a golden yellow color with some browner (older) spots and silvery (younger) areas where air is trapped in the mantle. The emanating brown hyphae of various thicknesses have numerous 90^0 branchings forming a fine loose network around the mycorrhizal tips. Probe 1NA from unlimed soil at 0-10 cm depth, spring 1999. 250x. Photo 1-19.

Figure 12-15B: *Fagirhiza tubulosa* autofluorescence < 1 mm from tip. The fresh samples from the limed soil were easily destroyed upon sectioning, as shown here. The mantle had a pale green autofluorescence but because of how easily these tissues fragmented a proper comparison to the hardier unlimed samples could not be made. Probe 4K from limed soil at 0-10 cm depth in spring 1999. Cx. 400x. Photo 39-5, clear filter, 30 second exposure.

12·15



Appendix 12- 16: Genea hispidula

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Genea hispidula* was found primarily at 0-10 cm depths in moist limed soils in spring. In moist fall soil, the limed and unlimed distribution was similarily low (Appendices 7-16 and 8A-B3-20).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 57. (Figure 12-16A).

Fungal Autofluorescence: In unlimed soil, thick (healthy) tips of *Genea hispidula* were isolated in the spring of 1999. The brown emanating hypha autofluoresced blue while the outer mantle and Hartig net cells were orange. As the season progressed to fall 1999, the fungal cells became pale orange. In the spring of 2000, the thin mantle and hyphae were non-fluorescent but the Hartig net was very pale orange. In the fall of 2000, the tips were once again thicker with non-fluorescent emanating hyphae, bluish-yellow outer mantle and a very pale orange inner mantle. Although the general morphology of the mantle cells remained consistent, desiccation stress during fall of 1999 had a long term effect on the deposition of fluorescent chemicals within the fungal walls (Figure 12-16B).

In limed soil the emanating hyphae and outer mantle cells were consistently non-fluorescent while the Hartig net cells varied from yellow-orange (spring 1999) to pale orange (fall 1999) to pale yellow (spring 2000) to very pale orange (fall 2000) with the progressing seasons. The limed samples were more consistent (less variable) than the unlimed samples. In the few tips extracted from 30-40 cm depth, the root cells had a poor Hartig net and all the fungal cells were non-fluorescent. Changes in fluorescence indicate a sensitivity response to desiccation. *Genea hispidula* growing on unlimed soil was more responsive to stress while liming, at least in this case, improved survivability.

Root Autofluorescence: In unlimed soil, the xylem was blue. Phloem varied from faint yellow (spring 1999) to extremely faint orange (fall 1999) to non-fluorescent (spring and fall 2000). The pericycle was normally bright blue except for fall 1999 when it was blue-green. The endodermis was yellow (spring 1999) to blue-green (fall 2000) to bright blue (spring & fall 2000). The cortex was bright blue except for the spring of 1999 when it was orange to yellow. The hypodermal and epidermal cells matched the orange Hartig net cells

In limed soil, the root cells fluoresced typical blue except for in spring 1999 when the xylem was yellow and in spring 2000 when, in one tip, the cortex was pale orange-yellow. The phloem was normally non-fluorescent except for spring 1999 when it was pale orange. The hypodermal and epidermal cells exactly matched the yellow-orange Hartig net cells. In the few tips isolated from 30-40 cm depth, with poor mycelial infiltration, the xylem, cortex, hypodermal and epidermal cells all fluoresced blue to pale blue while the phloem, pericycle and endodermal cells were orange.

Fungal Aluminum: In unlimed soil the emanating hyphae and Hartig net cells were Al-free but the outer mantle cells contained Al in the fall 1999 and fall 2000. In limed soil, all the fungal cells were Al-free except for spring 1999 when specks of Al and some wall deposition was evident. In samples from 30-40 cm depth, specks of Al were present.

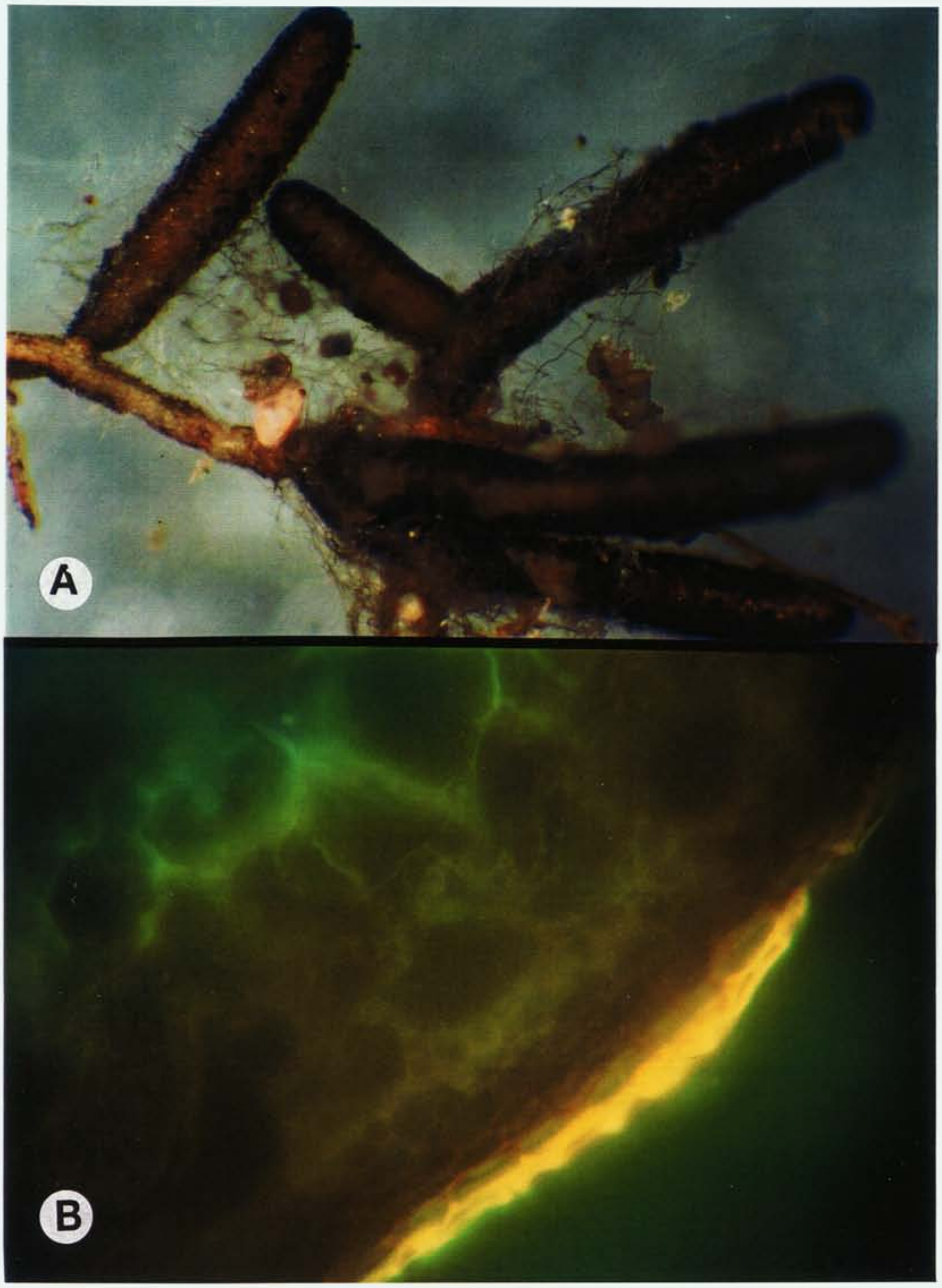
Root Aluminum: In the unlimed soil, the xylem and cortex consistently contained Al which most strongly present in the spring of 1999. The outer endodermal wall (outside the casparian barrier) contained Al in spring 1999. A decline in cortical Al was associated with a loss of fluorescence in the external fungal walls. In limed soil, the xylem contained Al while the phloem, pericycle and endodermis were generally Al-free except for one questionable sample (spring 2000). In the spring of 1999 the Al content of the cortical cells was faint while the following spring it was relatively strong. The fall samples were more variable with some cortical cells being totally Al-free even during the drought.

Summary: The genus *Genea hispidula* grows year round but prefers 0-10 cm depth limed soil. The outer root cells and their tightly associated intervening hyphae are strongly similar in autofluorescence implying similar chemical cell wall deposits. Separately the hyphae of this species were primarily non-fluorescent. Tips isolated from unlimed soils seemed more sensitive to drought while tips from limed soils seemed less affected with generally less Al sequestration in the mantle and root cell walls.

Figure 12-16A: *Genea hispidula* gross morphology. Monopodal system with branched brown mantle covered tips with numerous emanating hyphae and adhering debris. Probe 1000K from limed soil at 0-10 cm depth in fall 2000. 160x. Photo 12-18.

Figure 12-16B: *Genea hispidula* autofluorescence < 1 mm from tip. The fungal mantle autofluorescence varied with season and soil depth. Here the outer mantle has some very bright yellow regions and some deeper non-fluorescent areas while the Hartig net is dull olive green and the cortical cells are blue to blue green. Probe 900N from unlimed soil at 0-10 cm depth in fall 2000. Cx. 1000x. Photo 28-13, clear filter 120 second exposure

12·16



Appendix 12-17: Genea verrucosa

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare. *Genea verrucosa* was isolated from 0-10 cm depth in the fall of 2000 from both the limed and unlimed plots (Appendices 7-17 & 8A-B3-21).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 120.

Fungal Autofluorescence: In unlimed soil, the fungal cells are primarily non-fluorescent but some outer mantle cells were pale yellow. In limed soil, the hyphae were non-fluorescent while the mantle cells were either non-fluorescent or sometimes yellow and in the Hartig net area they were pale orange (Appendix 7-17), (Figure 12-17A).

Root Autofluorescence: The xylem, pericycle and endodermis were bright blue while the cortex was pale blue and the phloem was non-fluorescent. The hypodermal and epidermal cells matched the fungal hyphae. In unlimed soil the hypodermal and epidermal cells were non-fluorescent while in the limed soil they were often faint orange (Figure 12-17A).

Fungal Aluminum: In both limed and unlimed soil, the emanating hyphae and Hartig net cells were Al-free while the outer mantle cells were variable either being Al-free or contained some Al (Figure 12-17B).

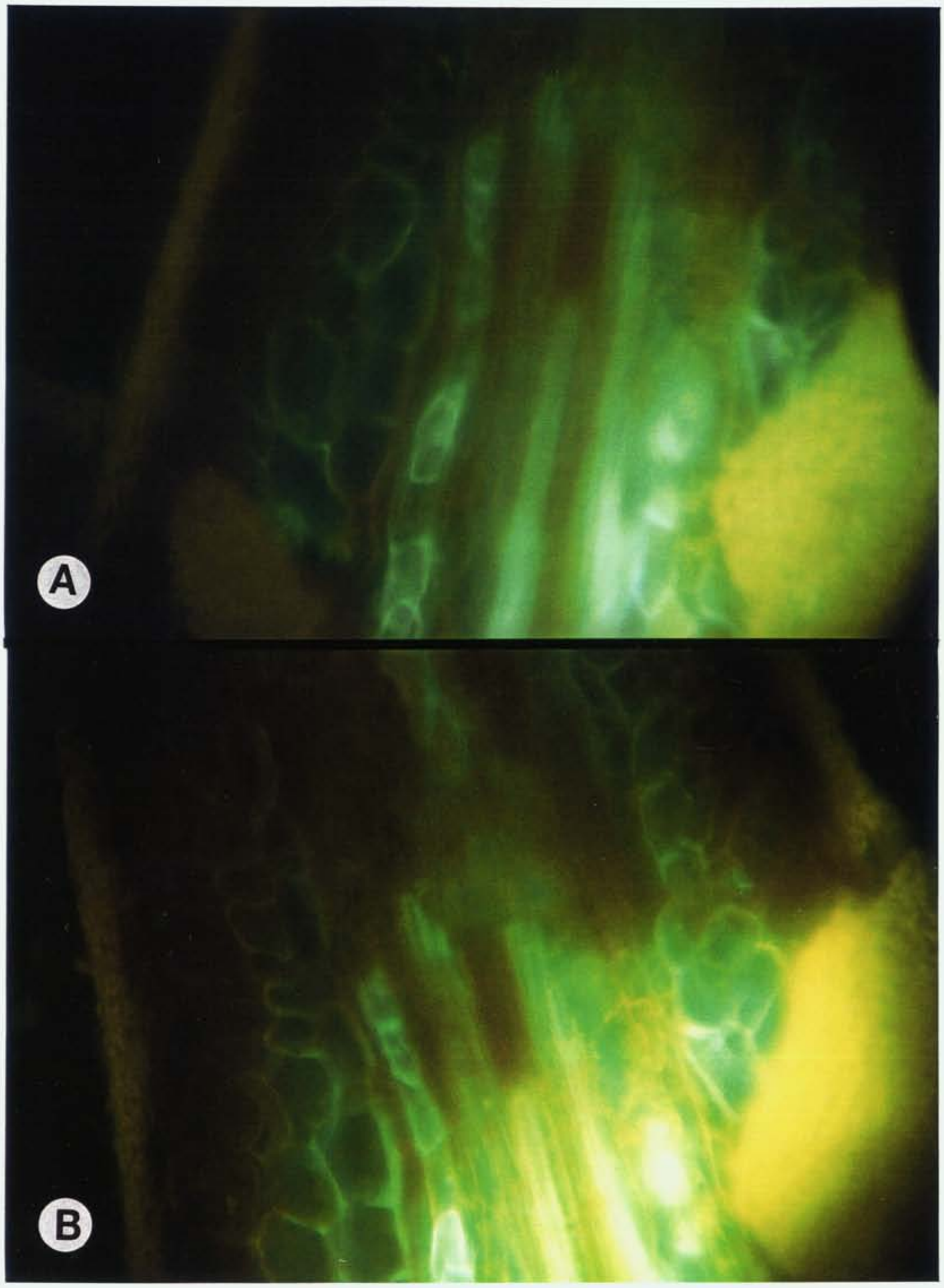
Root Aluminum: In both limed and unlimed soil, the xylem contained Al while the phloem, pericycle and endodermis were Al-free. In roots from unlimed soil however the cortical cells were variable either being Al-free or containing some aluminum. In roots from limed soil Al was faintly but consistently present (Figure 12-17B).

Summary: *Genea verrucosa* tips from unlimed soil seemed to have a slight advantage (less Al) over those from limed soil however this species was a rare in both zones.

Figure 12-17A: ***Genea verrucosa*** **autofluorescence < 1 mm from tip.** The outer mantle is very faintly green-yellow while the Hartig net is non-fluorescent on the left side of the image. The root cells are typical blue to blue-green and on the very right is a large patch of dislocated mantle which can be seen fluorescing yellow (left) to green (right). Probe 900K from limed soil at 0-10 cm depth in fall 2000. Lx. 400x. Photo 32-30, clear filter, 15 second exposure.

Figure 12-17B: ***Genea verrucosa*** **with Morin < 1 mm from tip.** The xylem and cortex showed aluminum content in spots in relation to where the mantle also showed aluminum content. Probe 900K from limed soil at 0-10 cm depth in fall 2000. Lx. 400x. Photo 32-31, clear filter, 30 second exposure, 5 minutes after Morin treatment.

12-17



Appendix 12-18: Hydrum rufescens

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Hydrum rufescens* was found only in the limed forest in spring 1999 and so has no comparative value but was included here because of the strong Al content in the cortex and xylem and concurrent absence in the fungal sheath. Dramatically showing that if Al passes the sheath it strongly accumulates in the susceptible root cells.

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 92.

Fungal Autofluorescence: Outer mantle is non-fluorescent to blue while the poor Hartig net is faint yellow. The outer mantle is very thin, easily damaged in sectioning and poorly represented in cross-sections (Figure 12-18A).

Root Autofluorescence: Typical.

Fungal Aluminum: None (Figure 12-18B).

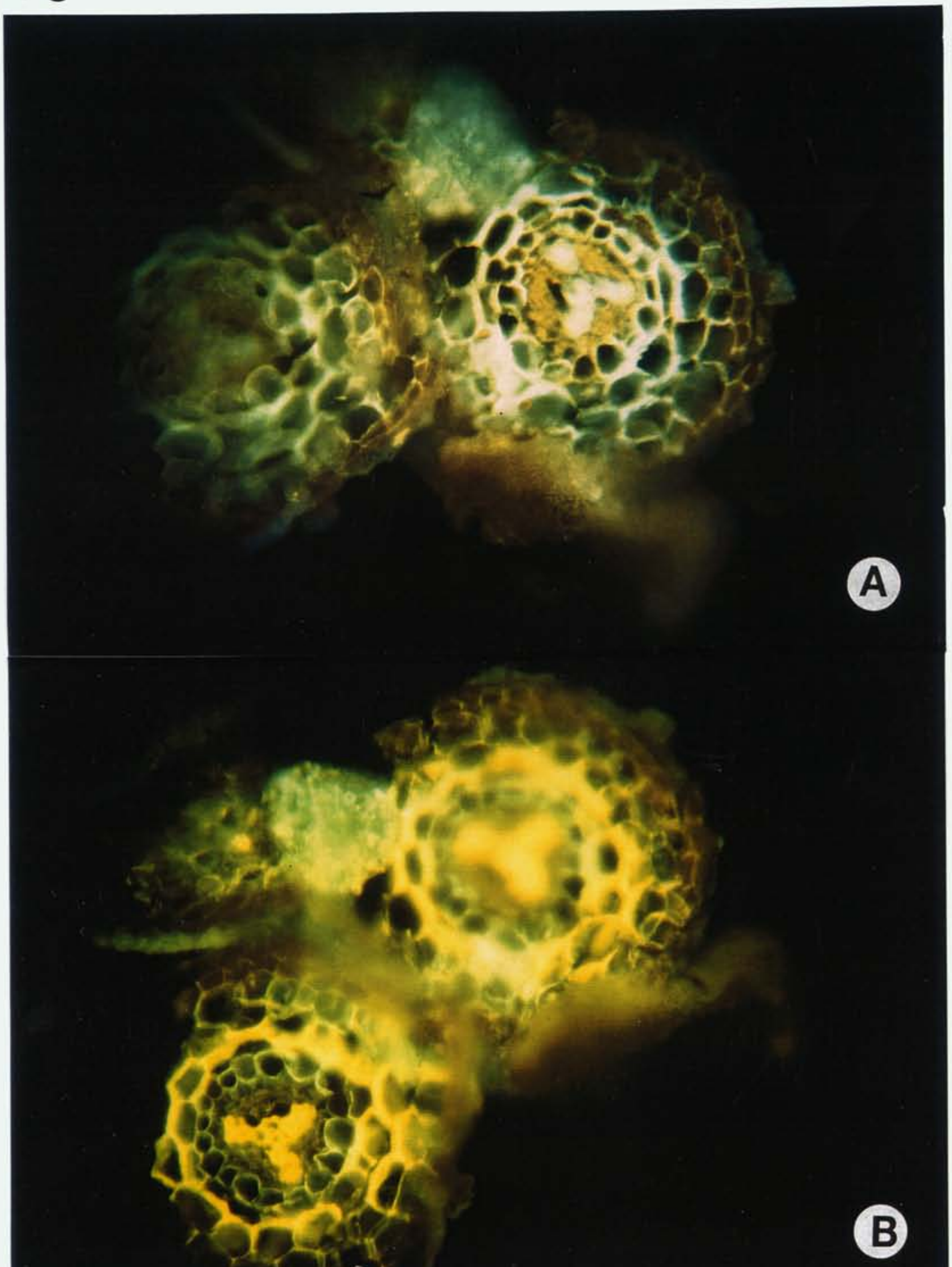
Root Aluminum: Extremely strong Al content in the phloem (Figure 12-18A) and cortex and xylem (Figure 12-18B).

Summary: The limed zone had more mycorrhizal diversity than the unlimed although each species represented was generally low in tip numbers, weight and smaller in size. *Hydrum rufescens* was one of these species found rarely and only in the limed soils. It was never very healthy in appearance making identification difficult. Despite the fact that Hydrum rufescens does not apparently accumulate toxic Al it is very dependent upon the root for survival and the dramatic accumulation of Al within the root, probably leading to loss of function and therefore loss of sugar movement to the dependent mycorrhiza may account for the poor appearance of the mycorrhiza. But, in addition to this it needs to be noted that *Hydrum rufescens* is not a "normal" oak mycorrhiza but rather a probable transition species crossing over from its typical host *Picea abies* which grows outside the area tested.

Figure 12-18A: ***Hydnum rufescens*** **with Morin < 1 mm from tip.** The initial few minute after exposure to the Aluminum reagent Morin, there was a tiny change in normal blue or non-fluorescent regions. The first region to show Al was, unusually, the phloem which generally is a non-reactive zone in most roots examined. Probe 1KA from limed soil at 30-40 cm depth in spring 1999. Cx. 250x. Photo 9-35, clear filter 15 second exposure, 5 minutes after Morin treatment.

Figure 12-18B: ***Hydnum rufescens*** **with prolonged Morin exposure.** The same section as shown in Figure 12-18A, the pair of root cross-sections have floated a little and now exhibit very strong aluminum content in the cortex and xylem while the phloem has dulled and the endodermal ring remained blue or non-reactive. The disrupted mantle which is mostly blurred in this image shows minimal Al content which mostly an artifact due to the intense brightness of the root walls. Probe 1KA from limed soil at 30-40 cm depth in spring 1999. Cx. 250x. Photo 9-36, clear filter 15 second exposure, 7 minutes after Morin treatment.

12-18



Appendix 12-19A: Inocybe appendiculata

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Inocybe appendiculata* was isolated only in the fall of 2000 from unlimed and limed soil at 0-10 cm depths (Appendices 7-19 and 8A-B3-23).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 94.

Fungal Autofluorescence: In the unlimed soil, the mantle cells were yellow green while the Hartig net cells fluoresced faint orange. In the limed soil, the mantle cells were bright blue while the Hartig net cells were non-fluorescent. This was a dramatic enough difference to require a double check of the species identification, but all was in order, but that does not eliminate the possibility of subspecies or allelic variation.

Root Autofluorescence: In both unlimed and limed soil, the xylem, pericycle and endodermis fluoresced bright blue while the phloem was non-fluorescent. In unlimed soil the cortical cells were faint yellowish blue while in limed soil they were faint blue. The hypodermal and epidermal cells matched the Hartig net cells and so were pale orange in unlimed soil and non-fluorescent in the limed soil.

Fungal Aluminum: In both unlimed and limed soil, Aluminum was strongly present in the mantle but only faintly present in the Hartig net.

Root Aluminum: In unlimed soil, Al was present only in the root cortex and absent everywhere else including the xylem. In limed soil, Al was absent from the cortex but variably present in the xylem.

Summary: Despite the fact that in both unlimed and limed soil, the fungal cells of *Inocybe appendiculata* sequestered aluminum, there were marked differences in the xylem content. There was more Al in the xylem of the limed roots.

Appendix 12-19B: Inocybe obscurobadia

Fruiting body Occurrence: None, although *Inocybe fastigiata* and *Inocybe praetervisa* were found in fall 2000 in both the unlimed and limed plots. (Appendix 2C).

Mycorrhizal Occurrence: *Inocybe obscurobadia* was present at 0-10 cm depth and seems to have a preference for spring growth. Many tips were found in the fall of 1999 in the unlimed soil at both 0-10 and 50-60 cm depth, but it was felt that these may have been a subspecies despite the morphological similarities and so were not included in the fluorescence analysis (Appendices 7-18 and 8A-B3-24).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 96. Figure 12-19A shows the silvery mantle with trapped air and a few of the emanating hyphae.

Fungal Autofluorescence: In unlimed soil, the hyphae and outer mantle were orange to yellow-orange while the outer Hartig net was pale orange and the inner Hartig net varied from pale blue to pale orange (Figure 12-19B). In limed soil, the hyphae and outer mantle were orange while the outer Hartig net was pale orange and the inner Hartig net was non-fluorescent or blue (Figure 12-19B).

Root Autofluorescence: In unlimed soil, the xylem, pericycle and endodermis fluoresced bright blue and the phloem was non-fluorescent. The cortex however was variable (faint blue to bluish yellow to blue to faint yellow to yellow). The hypodermal (pale blue or orange) and epidermal (pale orange) cells matched the fungal colorations (Figure 12-19A). In limed soil, the xylem fluoresced bright blue but the pericycle and endodermis were pale blue and the phloem was non-fluorescent. The cortex was very pale blue. The hypodermal (non-fluorescent) and epidermal (pale orange) cells matched the fungal colorations (Figure 12-19B).

Fungal Aluminum: In the unlimed soil, Al was strongly present in the hyphae and outer mantle but variable in the Hartig net region sometimes being present (spring 1999) or absent or faint (spring 2000). In limed soil, Al was less strongly present in the hyphae and outer mantle, absent from the outer Hartig area but faintly present in the inner Hartig net.

Root Aluminum: In unlimed soil, Al was faintly present in the xylem and variably present in the cortex being somewhat more strongly evident in spring 1999 and reduced in spring 2000 and absent elsewhere. In limed soil, Al was more strongly present in the xylem but absent from the cortex and elsewhere.

Summary: *Inocybe obscurobadia* was a shallow soil spring mycorrhiza but fall fruiting species. Both unlimed and limed probes contained Al in the hyphae and outer mantle cells, but with less evident in the limed samples. Despite this it is hard to say which was more beneficial to the tree. In the limed samples the absence of Al from the cortex but a strong presence in the xylem would indicate either strong point uptake at the mycorrhizal root apex or strong sequesterization by the xylem walls. Since there was no obvious accumulation of Al in xylem regions <1 mm from the tip, the latter hypothesis is more likely indicating strong uptake and rapid initial translocation to the xylem, accumulating in older xylem regions, distal to the tip. In the unlimed probes variable sequestration of Al in the cortical cells resulted in less accumulation in the xylem. The mycorrhizae then controlled access to the root cells but free Al moved to the xylem and accumulated.

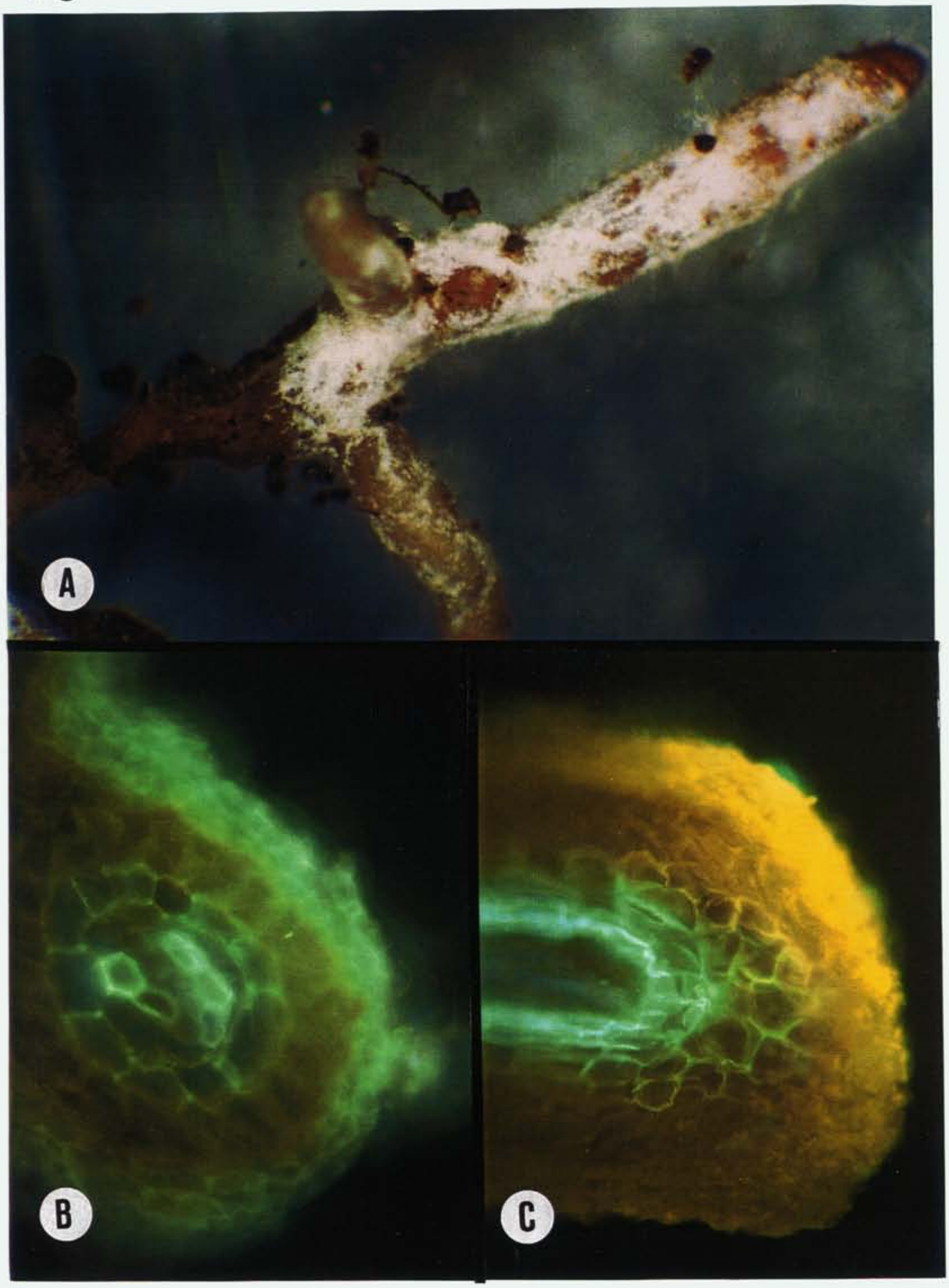
There were an insufficient number of samples available to come to any firm conclusions concerning this Genus species-root interaction, but in general, if liming allows free translocation to the xylem and less accumulation in the cortex, the temporal advantage for the tree would be greater root survival at the expense of increased Al translocation to the above soil structures. Conversely, in unlimed soil, if more aluminum is sequestered in the fungal and cortical cells, then the increasing concentrations may threaten the health status of the mycorrhizal roots but reduce the overall translocation of potentially toxic ions to the above ground structures.

Figure 12-19A: ***Inocybe obscurobadia*** **gross morphology.** The monopodal-pyramidal mycorrhizal system has a silvery appearance due to air trapping. The base of the ramified system shown is brown as are spots in the mantle where air is absent or the mantle is damaged. The long tip is brown, damaged and a lateral shorter tip is still silvery brown implying air loss but no damage. There is one brown rhizomoprh strand near the aforementioned lateral tip and fine emanating hyphae are visible along the long tip. Probe 100K from limed soil at 0-10 cm depth, spring 2000. 140x. Photo 2-23.

Figure 12-19B: ***Inocybe obscurobadia*** **autofluorescence, limed tip.** The region < 1 mm from the tip shows a green-blue autofluorescence in the mantle and faint orange in the Hartig net. In other limed tips the mantle was more orange. The mantle has lost air and somewhat collapsed in the preparation process. Probe 7KA from limed soil at 0-10 cm depth, spring 1999. Cx. 400x. Photo 40-5, clear filter, 30 second exposure.

Figure 12-19C: ***Inocybe obscurobadia*** **autofluorescence, unlimed tip.** The region < 1 mm from the tip shows an intense orange autofluorescence in the mantle with duller orange in the Hartig net zone and bright blue in the cortical, endodermal and xylem cell walls. The unidentified orange chemical deposition may be associated with acidic soil. Probe 6NA from unlimed soil at 0-10 cm depth, spring 1999. Lx. 400x. Photo 40-2, clear filter, 60 second exposure

12-19



Appendix 12- 20: Laccaria amethystina

Fruiting body Occurrence: Extremely common in both forests in fall 2000 (Appendix 2C). No fruiting bodies were found in the very dry fall 1999.

Mycorrhizal Occurrence: *Laccaria amethystina* mycorrhizae were strongly present in the wet spring and fall of 2000 from 0-10 cm depth soil in both unlimed and limed plots (Appendices 7-20 and 8A-B3-25).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 18. In gross morphology this species was most readily identified by its white velvet mantle with amethyst colored tips and many fine white emanating hyphae (Figure 12-20A).

Fungal Autofluorescence: The outer mantle cells were variable in their fluorescence often forming three layers with a duller layer sandwiched between two brighter layers. In addition while in unlimed soil the outer mantle tended to be yellowish in the spring and greenish in the fall (Figure 12-20C); in the limed soil the reverse trend was apparent (Figure 12-20G). The Hartig net cells all tended to be very faint orange-blue in the spring to light orange-blue in the fall.

Root Autofluorescence: In unlimed soil, the xylem fluoresced bright blue, while the pericycle and endodermis varied from blue-green (spring 2000) to bright blue (fall 2000), the cortex was pale blue and the phloem was non-fluorescent (Figure 12-20C). In limed soil, the xylem, pericycle and endoderm were bright blue, while the cortex fluoresced from pale to very pale blue, and the phloem was non-fluorescent (Figure 12-20G).

Fungal Aluminum: In the unlimed soil, the mycorrhiza was Al-free in spring 2000 and questionably contained Al in the fall of 2000 as evidenced by a greenish fluorescence (Figures 12-20 D, E, F). In the limed soil, the mantle definitely contained Al both spring and fall 2000, while the Hartig net area was either Al-free or had very tiny amounts. (Figure 12-20H).

Root Aluminum: In the unlimed soil, in the spring 2000, the xylem and cortex definitely contained aluminum with some possibly evident in the pericycle and endodermis but none in the hypodermis and endodermis or the outer fungal mantle. In the fall 2000, aluminum was variably present in the xylem and faintly present in the cortex and Hartig net area and mantle but absent from the pericycle and endodermis (Figure 12-20 D, E, F). In limed soil, the xylem cell walls were occasionally Al-free while other walls contained Al. The phloem, pericycle and endodermis were Al-free. In spring in the cortical area Al was strongly present close to the endodermis and weakly present in distal areas including the hypodermis and epidermis and strongly held in the mantle. In the fall, Al was often absent from the cortex and Hartig net area but more strongly held in the mantle (Figure 12-20 H).

Summary: *Laccaria amethystina* held aluminum most strongly in the mantle cells in the limed soils, with little showing up in the xylem. Despite the absence of Al in the mantle of the unlimed roots where was generally less Al evident in the root proper and the xylem. From these results, it can be implied that the limed species had better Al-retention ability and in the unlimed species, Al was not sequestered.

Figure 12-20A: ***Laccaria amethystina*** **gross morphology.** Young mycorrhizae with violet tip, velvety surface and brownish older parts showing some emanating hyphae (lower left) and adhering debris. Probe 200K from limed soil at 0-10 cm depth, spring 2000. 240x. Photo 7-46.

Figure 12-20B: ***Morin crystal.*** The crystal was allowed to develop in the absence of mycorrhizal sections but in the presence of an 0.01 % aluminum solution (See Section E3-2B) to demonstrate the intense yellow fluorescence. 250x. Photo 36-5, clear filter, 60 second exposure.

Figure 12-20C: ***Laccaria amethystina*** **autofluorescence < 1 mm from tip.** The thick mantle and Hartig net are faint green and the remaining cells of the root are blue except for the non-fluorescent phloem. Probe 700N from unlimed soil at 0-10 cm depth. Cx. 400x. Photo 38-9, clear filter, 30 second exposure.

Figure 12-20D: ***Laccaria amethystina*** **with Morin < 1 mm from tip.** Only certain root regions showed aluminum penetration up to the outer cortex (bottom left). Probe 700N from unlimed soil at 0-10 cm depth. Cx. 400x. Photo 38-11, clear filter, 30 second exposure, 5 minutes after treatment.

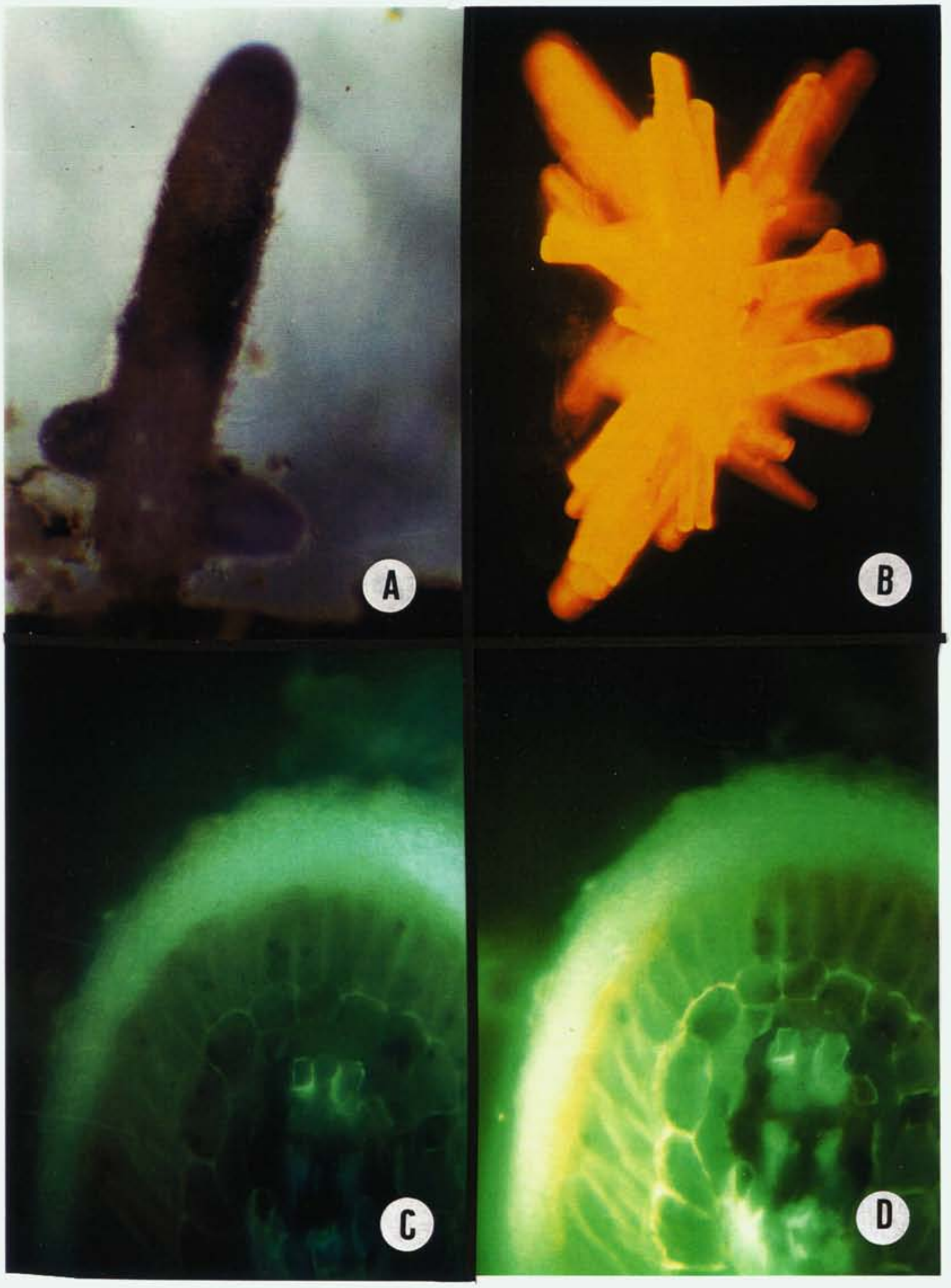
Figure 12-20E: ***Laccaria amethystina*** **whole tip with Morin.** The very tip, where the mantle is barely evident, was aluminum-free while the older regions, distal from the tip, where the mantle was thicker had faint indications which became stronger with distance from the tip. The aluminum content of the root corresponded. Probe 700N from unlimed soil at 0-10 cm depth in fall 2000. Lx. 250x. Photo 38-13, clear filter, 60 second exposure, 15 minutes after treatment.

Figure 12-20F: ***Laccaria amethystina*** **mantle detail with Morin.** The fungal region, about 1 mm from the tip shows some transition from Al-free (bottom) to Al-presence (top) in the inner mantle, Hartig net and cortical cells. Probe 700N from unlimed soil at 0-10 cm depth in fall 2000. Cx. 1000x. Photo 38-16, clear filter, 30 second exposure, 23 minutes after treatment.

Figure 12-20G: ***Laccaria amethystina*** **autofluorescence, limed probe.** The multitone nature of the mantle is more evident on the left root tip. Unlike the unlimed probes, the limed mantle was intensely fluorescent nearer the tip (left) and lost fluorescence with distance from the tip (right). Probe 800K from limed soil at 0-10 cm depth, fall 2000. Lx. 250x. Photo 37-33, clear filter, 90 second exposure.

Figure 12-20H: ***Laccaria amethystina*** **with Morin, limed probe.** There is no aluminum uptake evident near the tip, but if you look carefully at the older root area to the right, some aluminum is faintly evident in the inner cortical cells. Probe 800K from limed soil at 0-10 cm depth, fall 2000. Lx. 250x. Photo 37-33, clear filter, 90 second exposure, 5 minutes after treatment.

12-20



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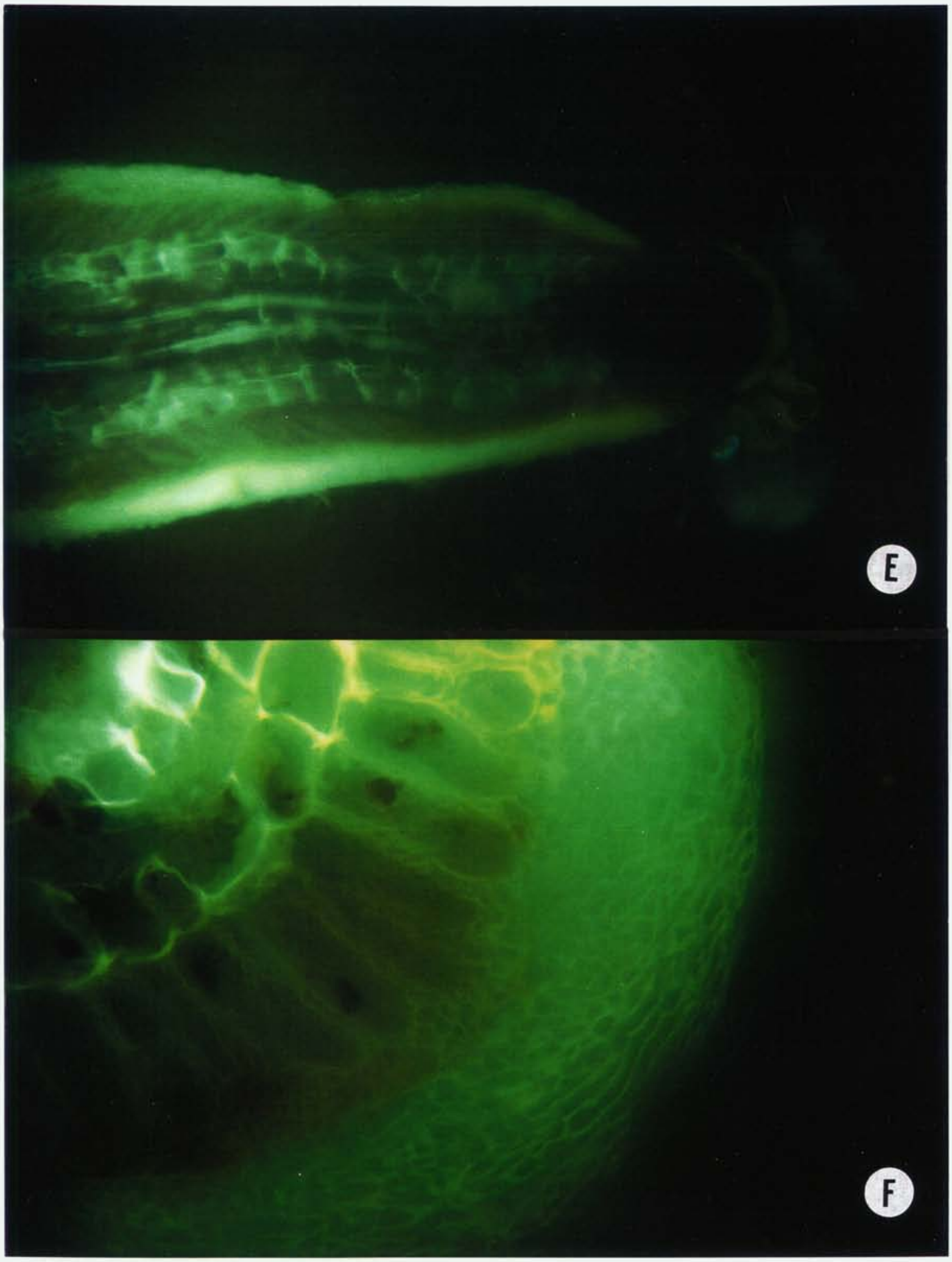

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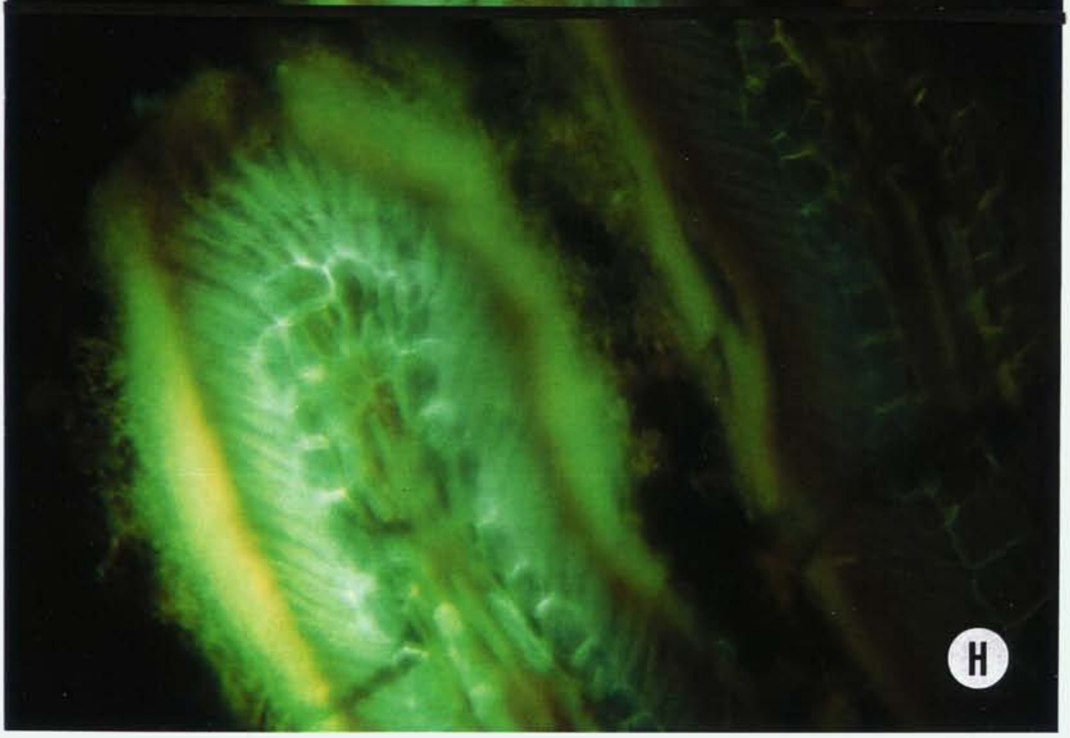


Appendix 12-21: Lactarius acris

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare. In spring 2000 *Lactarius acris* was isolated from 0-10 cm & 30-40 depths where it was most common in the unlimed soil, but in fall 2000, it shifted to the lower horizons and was more common at 30-40 cm (limed) and 50-60 cm (unlimed) depths (Appendices 7-21 and 8A-B3-26).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 72. Figure 12-21A.

Fungal Autofluorescence: The projecting hyphal tips and mantle fluoresced bright blue-green while the Hartig net was blue (Similar to: Figure 12-21B).

Root Autofluorescence: Typical. (Figure 12-21B).

Fungal Aluminum: In unlimed soil, the emanating hyphal tips and mantle were Al-free while the Hartig net contained faint evidence of Al close to the tip with concentration increasing with distance from the tip (Figure 12-21B). In limed soil, Al was strongly present in the mantle structures but less evident in the Hartig net (Figure 12-21C, D).

Root Aluminum: In both unlimed and limed soil, Al was usually strongly evident in the xylem, but absent from the phloem and endodermis. In the cortex aluminum appeared to graded with the weakest presence near the Hartig net and strongest near the endodermis. In unlimed soil, Al was often absent from the cortex, while it was variably present in the limed samples (Figure 12-21 B, C, D).

Summary: In unlimed soil, the mantle structures were often Al-free, but the cortex was variable. In limed soil, Al was often strongly present in the mantle structures but less evident in the cortex. In both cases, where Al was present in the cortex it exhibited a graded pattern of increasing intensity towards the endodermis. The sampling was consistent but too small to make any further generalizations.

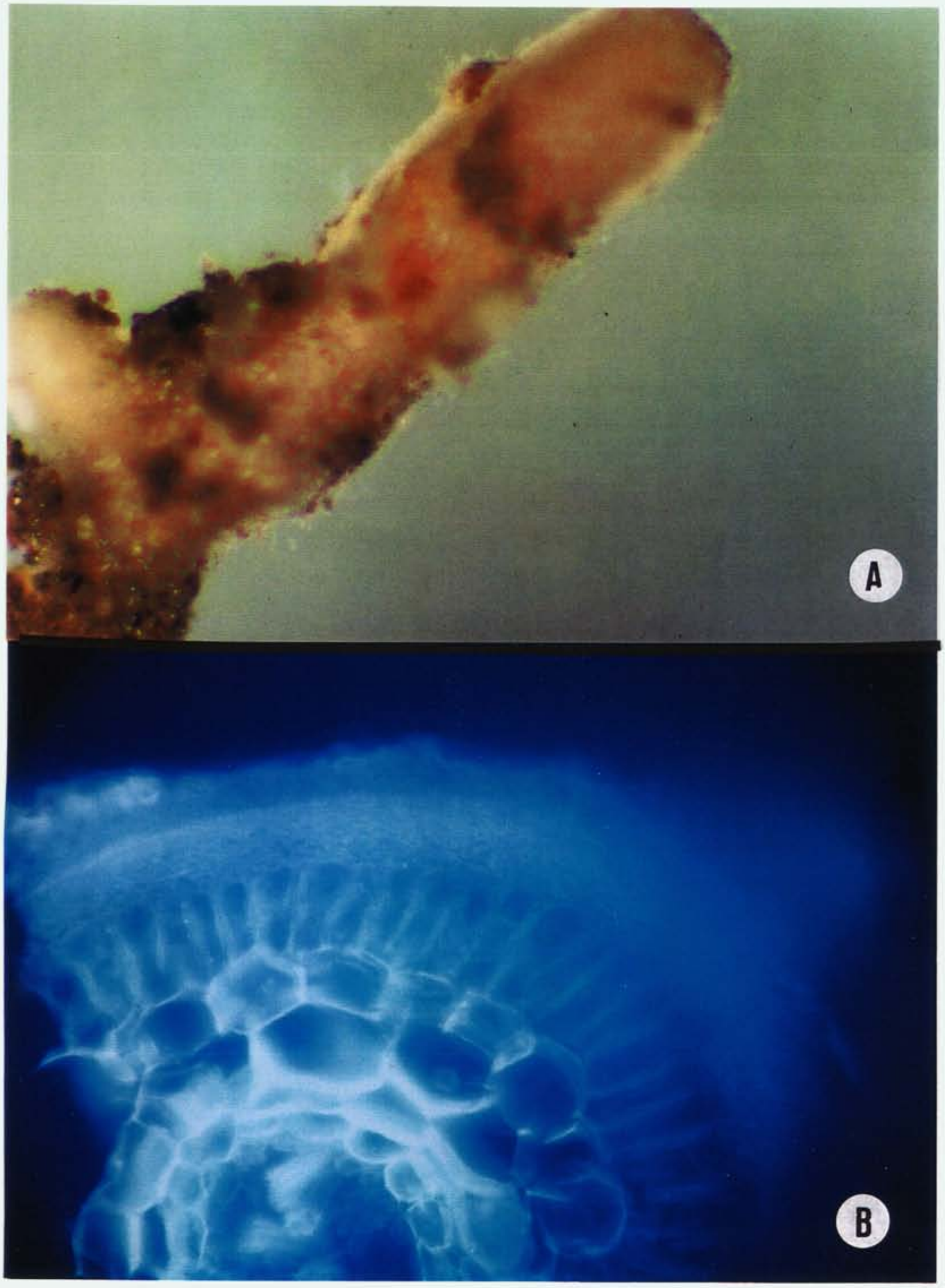
Figure 12-21A: ***Lactarius acris*** **gross morphology.** In air, the mycorrhiza has a rough surface, but under water (shown here) the projecting hyphal tips are barely visible. The axial and small lateral growths are covered with adhering debris particles. Probe 100N from unlimed soil at 0-10 cm depth in spring 2000. 290x. Photo 3-25.

Figure 12-21B: ***Lactarius acris*** **with Morin > 5 mm from tip, unlimed.** The intense blue of the mantle and roots cells shows no aluminum presence. Probe 1NA from unlimed soil at 0-10 cm depth in spring 1999. Cx. 400x. Photo 5-32, clear filter, 15 second exposure, 10 minutes after treatment.

Figure 12-21C: ***Lactarius acris*** **with Morin < 1 mm from tip, limed.** In stark contrast to the unlimed roots, the very thick limed mycorrhizal mantles fluoresced bright yellow to dull green with an extensive duller Hartig net indicating strong aluminum content. Probe 1000K from limed soil at 0-10 cm depth, fall 2000. Cx. 400x. Photo 22-31, clear filter, 20 second exposure, 5 minutes after treatment.

Figure 12-21D: ***Lactarius acris*** **with Morin.** Aluminum is more strongly evident in the mantle (upper right) and xylem (lower left) but less intense in the intervening cells of the Hartig net and cortex. It is absent from the blue endodermis. Probe 1000K from limed soil at 0-10 cm depth, fall 2000. Cx. 400x. Photo 22-32, clear filter, 20 second exposure, 15 minutes after treatment.

12-21



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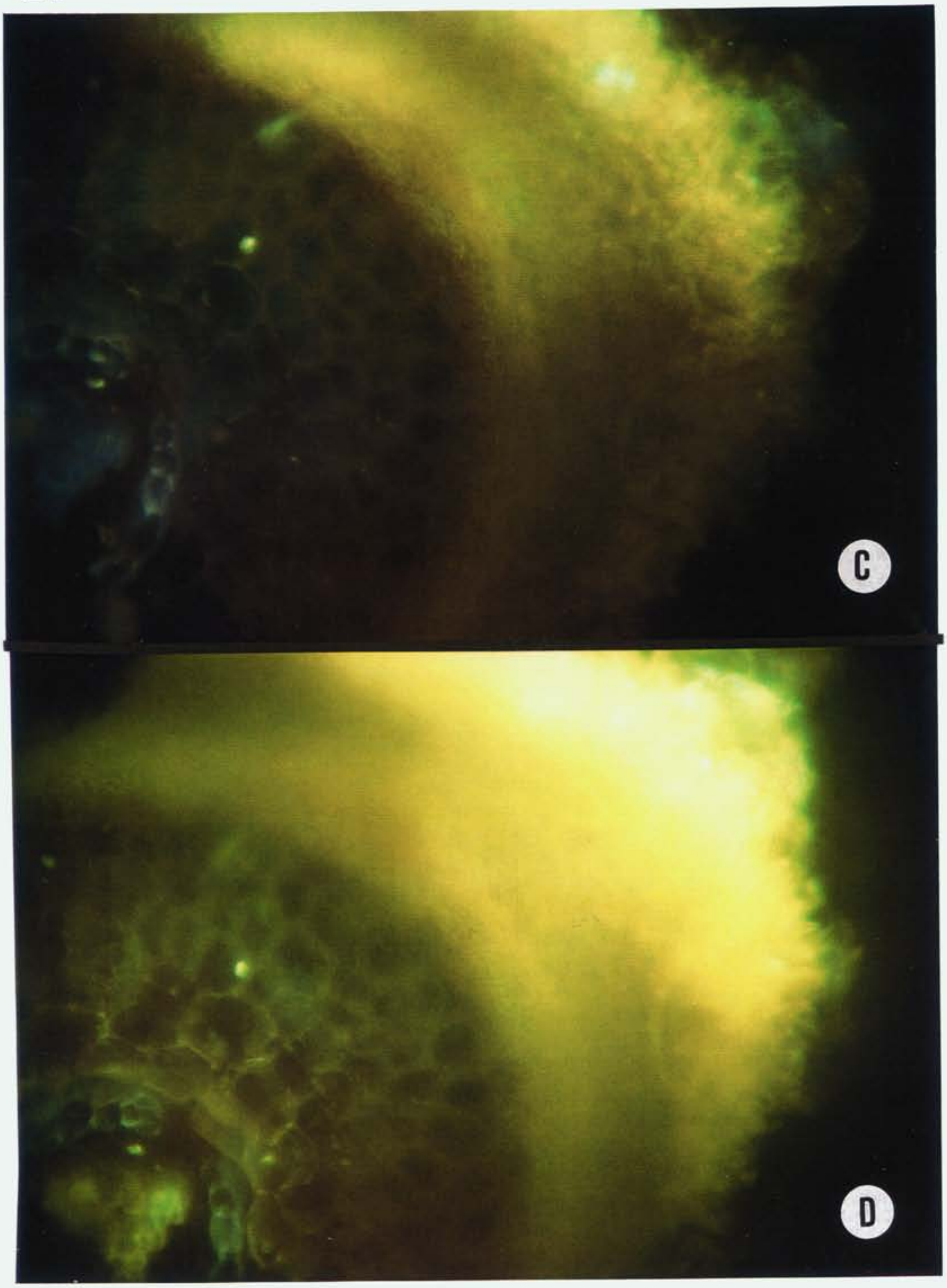


Appendix 12-22: Lactarius chrysorrheus

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare. *Lactarius chrysorrheus* was found in spring 2000 at 0-10 cm depth in both zones but was more common in 50-60 cm depth limed soil (Appendices 7-22 and 8A-B3-27).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 121. The white lactifer strands producing the reticulated appearance of the smooth mantle and rhizomorph surfaces was the primary identifying feature.

Fungal Autofluorescence: In unlimed soil the outer mantle fluoresced yellow while the Hartig net was orange-yellow. In limed soil the outer mantle was pale yellow to yellow- green and the Hartig net was pale orange. (Figure 12-22A).

Root Autofluorescence: Typical. (Figure 12-22A).

Fungal Aluminum: In unlimed soil the fungal cells lost fluorescent intensity in the presence of Morin indicating an absence of Al. In limed soil all the fungal cells were intensely yellow indicating strong Al presence (Figure 12-22B).

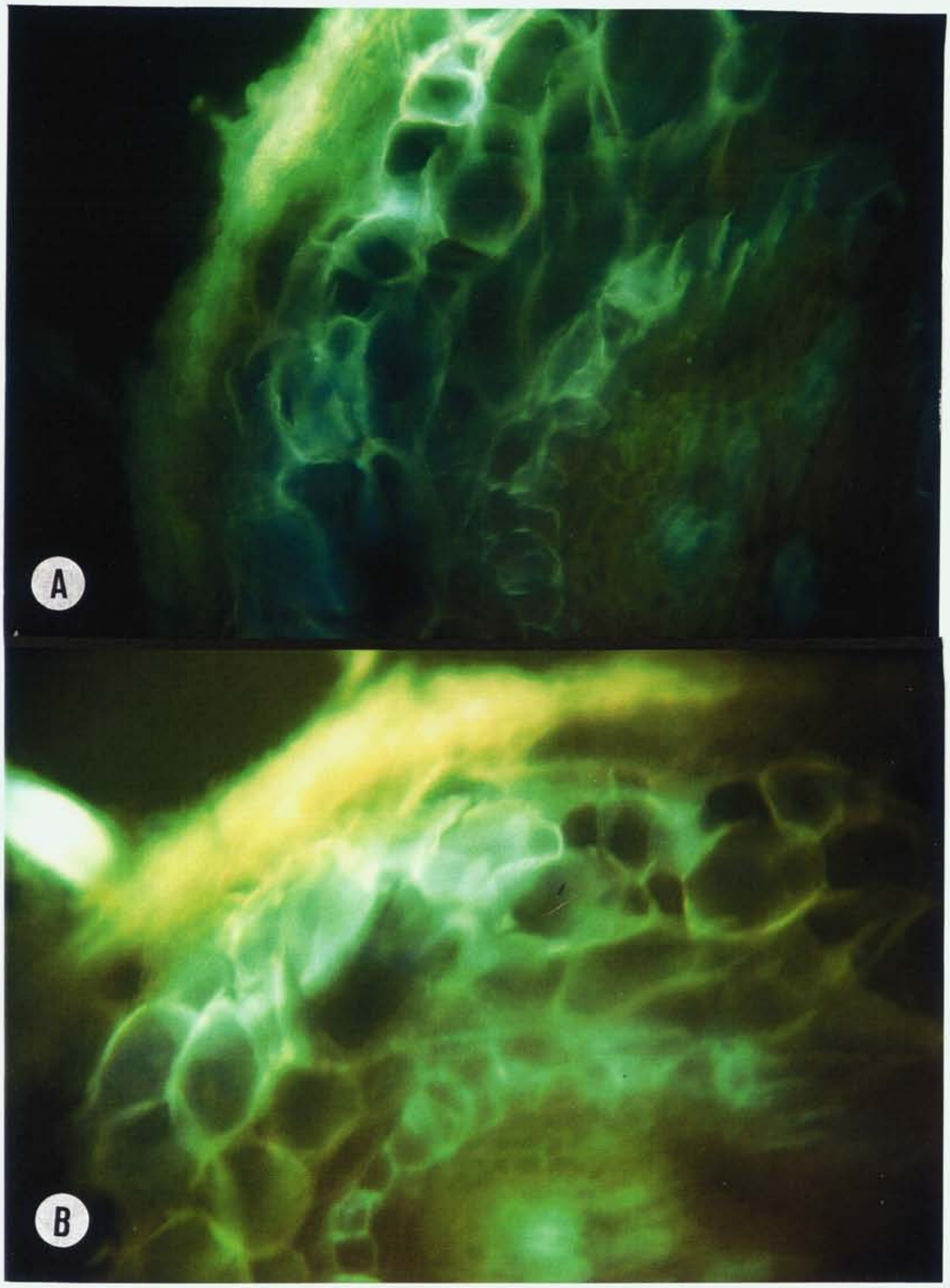
Root Aluminum: In unlimed soil, Al was strongly present in the xylem, weakly and present in the phloem, absent from the endodermal layers and relatively abundant in the cortex despite its apparent lack in the fungal sheath. In limed soil, Al was absent from the xylem, weakly present in the phloem, absent from the endodermal layers and variably present in the cortex with more Al near the stele and less evident near the hypodermis with strong concentrations in the fungal sheath (Figure 12-22B).

Summary: In unlimed soil, the mantle provided no barrier to Aluminum which seemed to translocate freely via apoplastic routes to the xylem. The presence of Al in the phloem may be due to return flow rather than uptake in the root since is was a rare event. In the limed soil Al appeared in alternating strong and weak deposition bands. This banding may indicate differences in physiological functioning of the pertinent cells or possibly accumulation at flow barriers.

Figure 12-22A: *Lactarius chrysorrheus* autofluorescence < 1 mm from tip. The mantle and collapsed Hartig net is dark to bright yellow-green while the root cells are blue and the phloem has faint orange fluorescence. Probe 200K from limed soil at 0-10 cm depth, spring 2000. Cx. 250x. Photo 30-18, clear filter, 40 second exposure.

Figure 12-22B: *Lactarius chrysorrheus* with Morin < 1 mm from tip. The mantle cells show strong aluminum content and despite the obvious disruption of the cortical region, the cortical cells are mostly Al-free. Probe 200K from limed soil at 0-10 cm depth, spring 2000. Cx. 250x. Photo 30-19, clear filter, 60 second exposure, 5 minutes after treatment.

12-22



Appendix 12-23: Lactarius pallidus

Fruiting body Occurrence: Absent fall 1999 and 2000, but present 2001 in the limed forest only.

Mycorrhizal Occurrence: *Lactarius pallidus* was found in unlimed soil at all depths and was most common at 0-10 cm in spring and fall 2000, but in limed soil it was present only in fall 2000 primarly at 0-10 cm depth (Appendices 7-23 and 8A-B3-28).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 59. (Figure 12-23A).

Fungal Autofluorescence: In unlimed soil at 0-10 cm depth the mantle cells fluoresced green-blue while the Hartig net cells were blue-green; at 30-40 cm depth all the fungal cells were bright blue and at 50-60 cm depth, the mantle cells were yellow-green and the Hartig net cells were blue-green (Figure 12-23C). In limed soil at 0-10 cm depth, the mantle cells were strongly bright green while the Hartig net cells were very faint yellow-green to faint yellow-orange < 1 mm from the tip and faint yellow-green > 5 mm from the tip; at 30-40 cm depth the mantle cells were faint yellow-green < 1 mm and faint green > 5 mm from the tip while the Hartig net cells were faint greenish-orange < 1 mm and blue-green to faint yellow-green > 5 mm from the tip (Figure 12-23B).

Root Autofluorescence: In unlimed soil, the xylem, pericycle and endodermal cells were bright blue. The cortical cells were bright blue at 0-10 and 30-40 cm depth but blue-green at 50-60 cm depth. The phloem cells were non-fluorescent at 0-10 and 50-60 cm but fluoresced blue at 30-40 cm depth (Figure 12-23C). In limed soil, the xylem, pericycle and endodermal cells were blue-green at < 1 mm and blue at > 5 mm from the tips in 0-10 cm depth samples but consistently blue at 30-40 cm depths. The cortex was yellow-green near the stele but non-fluorescent distal to the tip at 0-10 cm depth and consistently blue at 30-40 cm depth. The phloem was primarily non-fluorescent, but very faint orange at < 1 mm but not > 5 mm from the tips in 30-40 cm depth probes (Figure 12-23B).

Fungal Aluminum: In unlimed soil at 0-10 cm depth, Al was strongly present in the fungal cells with more Al present < 1 mm than > 5 mm from the tips. Conversely, the Hartig net cells contained more Al, distal to the tip. At 30-40 cm depth, the mantle contained more Al than the Hartig net cells and at 50-60 cm depth, the mantle was Al-free but the Hartig net contained moderate amounts (Figure 12-23D). In limed soil at 0-10 cm depth, the mantle cells were Al-free and the Hartig net contained a questionable amount of Al near the tip and none in areas > 5 mm distal. At 30-40 cm depth all the fungal cells contained modest to strong Al content in the limed probes (Figure 12-23B).

Root Aluminum: In unlimed soil at 0-10 cm depth while Al was strongly present in the fungal cells, it was absent or occasionally spotty in the cortex. At 30-40 cm depth, Al was strongly present in the fungal cells, cortex and xylem and at 50-60 cm depth it was absent from the fungal mantle but present in the Hartig net, cortical and xylem cells (Figure 12-23D). In limed soil at 0-10 cm depth, where Al was absent or questionably present in the mantle and Hartig net area, it was absent or variably present in the xylem and weakly to modestly present in the cortex. At 30-40 cm depth, where Al was variable in the mantle but present in the Hartig net, it was also present in the xylem and cortex (Figure 12-23B).

Summary: The only consistent feature of this species was its inconsistency implying a highly dynamic system. In general, at 0-10 cm depth, where Al was strong in the fungal cells, it was less evident in the unlimed root cells. In limed soil where the fungal cells were Al-free, the root cells accumulated Al. At 30-40 cm depth the unlimed and limed tips were more similar and both had more intense Al depositions in all cells except the phloem, pericycle and endodermis.

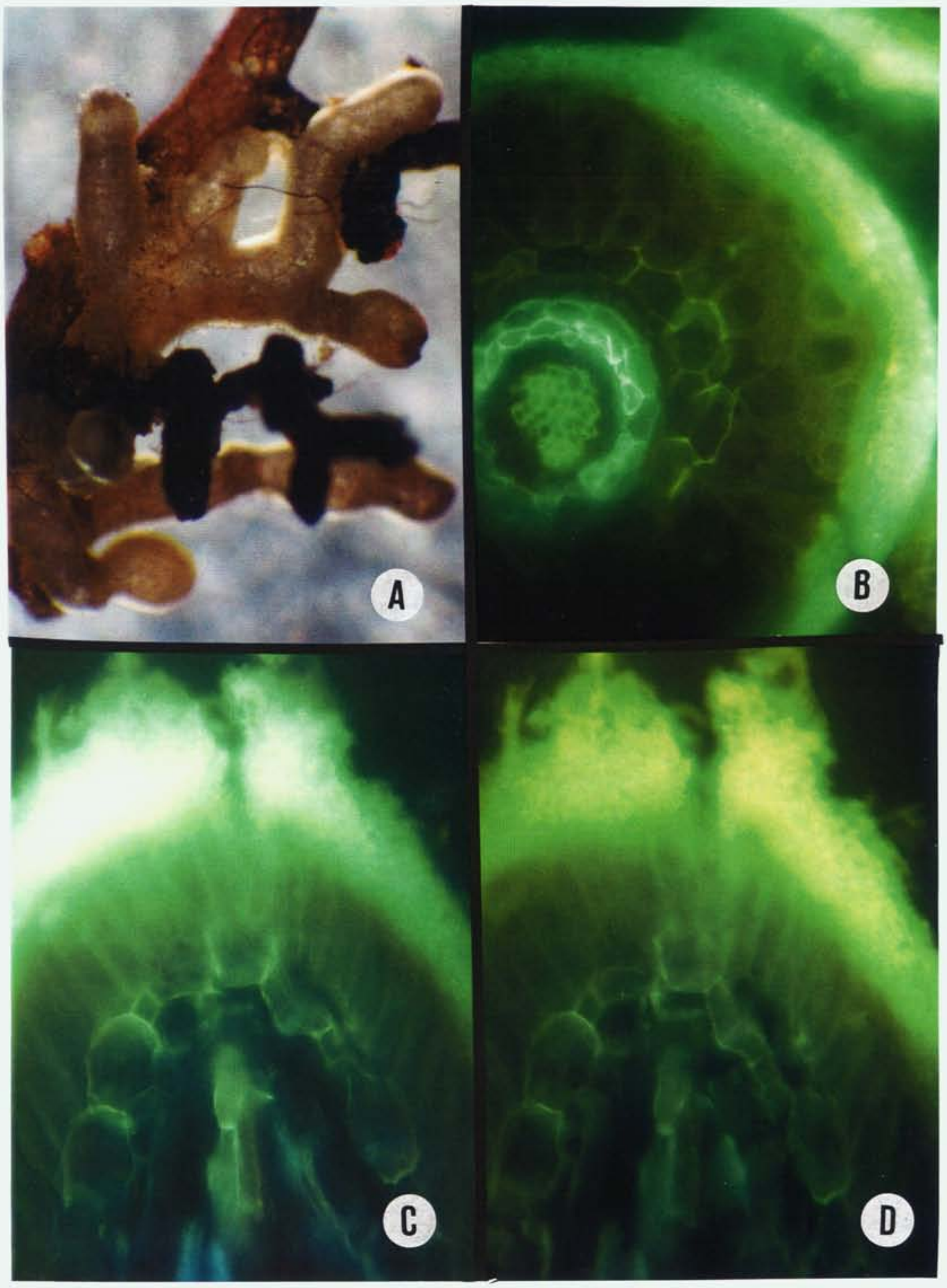
Figure 12-23A: ***Lactarius pallidus*** **gross morphology**. The pyramidal branching mycorrhizal system of pale tips is shown in contrast to an unknown dark mycorrhiza with dark emanating hyphae. The whitish veins of lactiferous hyphae are barely visible shining through the pale honey colored Lactarius mantle Probe 400N from unlimed soil at 0-10 cm depth in spring 2000. 180x. Photo 6-28.

Figure 12-23B: ***Lactarius pallidus*** **with Morin < 1 mm from tip, limed**. The very tip shows a thick bright green mantle with dull ochre Hartig net intertwining around unmodified cortical cells up to the innermost cortical layer. The endodermal/pericycle rings are bright blue-green as is the xylem zone. Although not shown, the autofluorescence was similar indicating no Aluminum content. Probe 1000K from limed soil at 0-10 cm depth in fall 2000. Cx. 400x. Photo 21-29, clear filter, 8 second exposure, 5 minutes after treatment.

Figure 12-23C: ***Lactarius pallidus*** **autofluorescence < 1 mm from tip, unlimed**. The mantle is bright green, Hartig net dull green and the root cells are blue. Probe 700N from unlimed soil at 0-10 cm depth in fall 2000. Lx. 400x. Photo 28-1, clear filter, 60 second exposure.

Figure 12-23D: ***Lactarius pallidus*** **with Morin < 1 mm from tip, unlimed**. The mantle shows strong evidence of aluminum. Probe 700N from unlimed soil at 0-10 cm depth in fall 2000. Lx. 400x. Photo 28-3, clear filter, 10 second exposure, 15 minutes after treatment.

12-23



Appendix 12-24: Lactarius rubrocinctus

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Lactarius rubrocinctus* was isolated in fall 2000 from 50-60 cm depth in both zones. it was also present in limed soil at 0-10 cm depth (fall 1999) and 30-40 cm depth (fall 2000) (Appendices 7-24 and 8A-B3-29).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 60. *Lactarius rubrocinctus* is very similar to *Lactarius subdulcis* in appearance except for scattered spots of reddish hyphae in octopus-like loose mounds which formed a direct contrast to the pale creamy yellow strands of the remaining mantle (Figure 12-24A).

Fungal Autofluorescence: In unlimed soil, the outer mantle cells were pale yellow and the inner cells non-fluorescent, while the Hartig net was pale orange (Figure 12-24B). In limed soil, the outer mantle cells were brighter yellow and the inner cells were orange, while the Hartig net was faint orange (epidermal zone) to blue (hypodermal zone).

Root Autofluorescence: Typical, except that in unlimed soil, the cortical cells were yellow-orange to yellow-green while in limed soil they were bright blue.

Fungal Aluminum: In unlimed soil, the orange fungal cells became paler and greener with Morin with some yellow specks in the Hartig net region (Figure 12-24B). In limed soil, the mantle cells were variable. At < 1 mm from the tip, the outer mantle strongly contained Al but the inner mantle cells were weaker and at > 5 mm from the tip, the outer mantle cells were weak in Al and the inner cells were Al-free. The Hartig net lost blue or orange fluorescence and took on a green tinge representing a questionable Al presence.

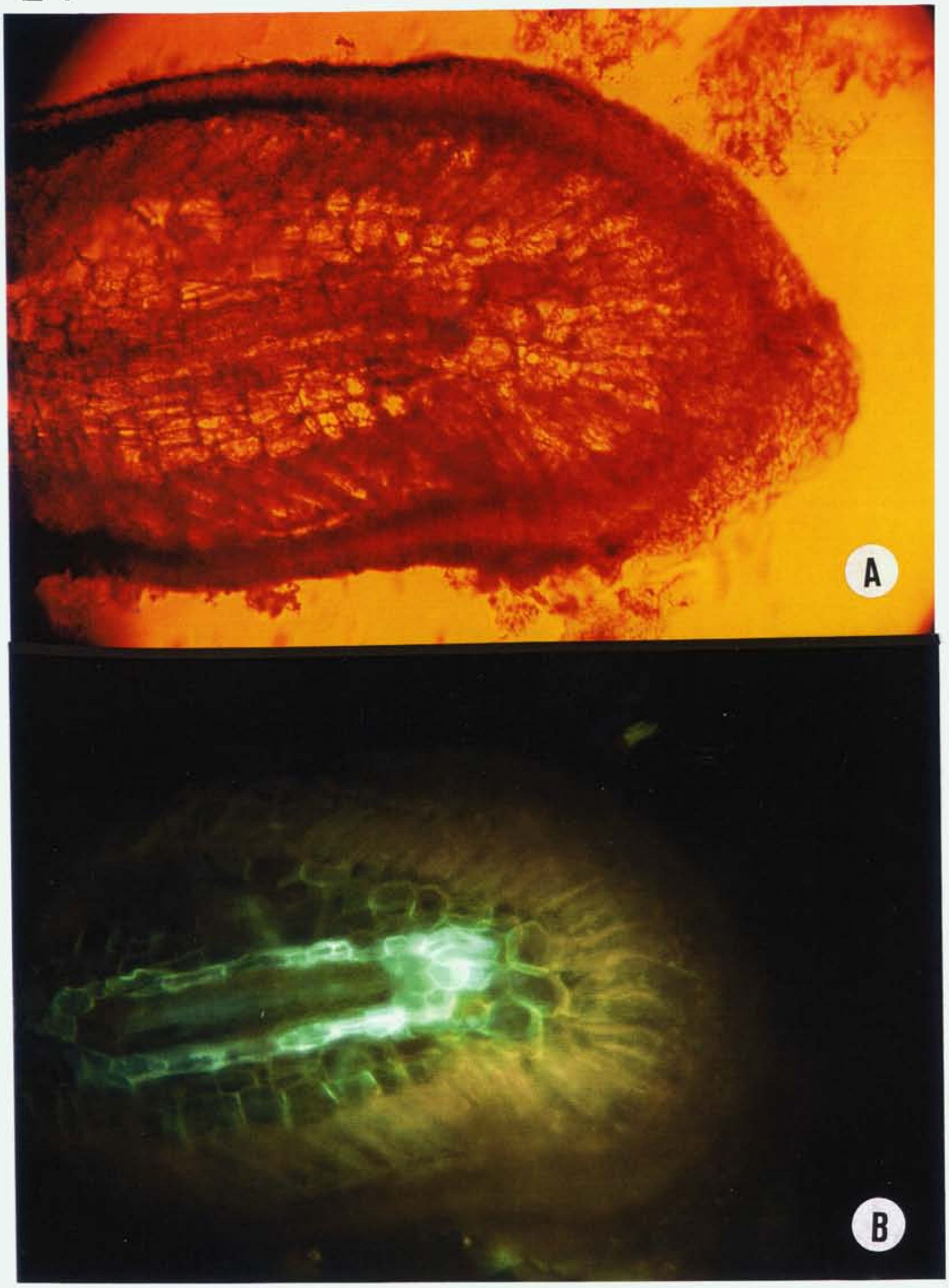
Root Aluminum: In both soils, the xylem very faintly indicated Al presence but the cortical cells strongly contained Al.

Summary: The limed probes contained more Al than the unlimed at 50-60 cm depth.

Figure 12-24A: *Lactarius rubrocinctus* tip. The whole tip appears reddish in white light with the surface mounds of loose reddish hyphae appearing darker red. Fragments of mantle cells are in the solution around the tip. The hyphae do not emanate. Probe 800N from unlimed soil at 50-60 cm depth in fall 2000. Lx. 250x. Photo 30-6, white light.

Figure 12-24B: *Lactarius rubrocinctus* tip with Morin. The fluorescence here is very similar to autofluorescence. The Hartig net and cortical cells were just beginning to show faint aluminum content. Probe 800N from unlimed soil at 50-60 cm depth in fall 2000. Lx. 250x. Photo 30-12, clear filter, 15 second exposure, 5 minutes after treatment.

12-24



Appendix 12-25: Lactarius subdulcis

Fruiting body Occurrence: Absent in the dry fall 1999, present in low numbers in the wet fall 2000, absent in the (intermediate) fall of 2001 in both forest zones (Appendix 2C)

Mycorrhizal Occurrence: *Lactarius subdulcis* was one of the most common mycorrhizal species. It was present in both unlimed and limed soils at all depths in the spring and fall samplings but was most common in fall 2000 in the unlimed soils at 0-10 cm depth (Appendices 7-25 and 8A-B3-30).

Mycorrhizal Morphology: Refer to Agerer (1987-1998). Plate 5. (Figure 12-25A, B).

Fungal Autofluorescence: In both unlimed and limed soils, the natural fluorescence of the mantle cells was various tints of green. In the spring and closer to the tip, the younger cells were often slightly more yellow-green and in contrast in the fall or further from the tip, the older cells were often greener and duller (Figure 12-25 C, E, G). The outer mantle cells were often more yellowish than the inner mantle cells (Figure 12-25C).

The Hartig net cells and the corresponding root cells were identical in color in most cases. Where the Hartig net was not fully developed, the natural blue fluorescence of the epidermal and hypodermal cells was apparent (Figure 12-25C). Where the Hartig net was fully developed, close to the tip the cells had a faint dull orange cast and further from the tip, especially in collapsed areas, the dull orange increased in intensity (Figure 12-25G). The deposition of greenish and ochre pigments seems therefore to be an aging phenomenon

Despite the distinct similarities in the specific autofluorescences in any given probe, there were marked differences in tint variations from season to season, in unlimed and limed soils and with depth implying a highly dynamic, responsive physiological system. It was difficult to distinguish obvious, consistent differences between unlimed and limed soil probes but some tentative differences did exist. The ability of *Lactarius subdulcis* to micro-adapt its wall chemicals to its environment may underlie its success in the rhizosphere.

Root Autofluorescence: In both the unlimed and limed soil, the xylem, pericycle and endodermis fluoresced faint to bright blue and rarely a random blue-green (Figure 12-25C, G). In fall 2000, the underdeveloped xylem and pericycle were non-fluorescent close to the tip. The phloem was normally non-fluorescent in the unlimed soil with a few exceptions when it fluoresced a faint orange (Fall 1999, 0-10 cm depth > 5 mm from the tip; Spring 2000, 30-40 and 50-60 cm depth, all tips; and Fall 2000, 50-60 cm depth, strongly orange). It was almost as if a mild "front" had moved downwards in the soil over the two year period. This was more obvious in the limed probes where the phloem was more frequently orange in tone than non-fluorescent. In spring 1999, at 0-10 cm depth, the older phloem cells were very faint orange, while in deeper soil, probes, all the phloem cells were faint orange. In fall 1999 and spring 2000, all the phloem cells were very faint orange, but in the fall of 2000, all the phloem cells had returned to the non-fluorescent state at 0-10 and 50-60 cm depth but were still variable at the 30-40 cm horizon. This time period coincides with the 1999 drought and delayed recovery period.

The cortical cells normally were blue in autofluorescence. In unlimed soil, the cortex was primarily faint to bright blue with only one exception (Fall 2000, 0-10 cm depth orange near the tip to faint green in distal areas). In limed soil there was much more variation in fluorescence from the normal. In spring 1999 the tones varied from blue-green (0-10 and 30-40 cm) to blue-yellow (50-60 cm). In fall 1999, at 50-60 cm depth the cortex had a yellowish tinge and in spring 2000, at 0-10 cm depth the older cells were orangish. In fall 2000 most cells returned to the blue-green tone while some were still faint orange.

It can be directly implied that the chemical producing the orange tone was associated with drought stress. If we accept this, then the second implication is that the limed roots were more stressed by the drought than the unlimed.

Fungal Aluminum: In unlimed and limed soils, Al was absent to variably present in the mantle and Hartig net cell walls at all depths. Very generally, sequestration was highly variable but if the mantle sequestered Al, then the interior cells were lower in relative content but if the mantle did not sequester Al, then the Hartig net cells compensated, exhibiting enhanced content (Figures 12-25 D, F, H).

More specifically, in unlimed soils, at 0-10 cm depth, Al was usually more concentrated in the mantle and outer Hartig net than in the inner Hartig net. Where it was absent in the Hartig net, it was still present in the mantle (dry Spring & Fall 1999) and when it was present in the Hartig net, it was occasionally absent from the mantle (Fall 1999, Spring & Fall 2000). Aluminum was most strongly present in mantle cells in the fall 2000, especially at > 5 mm from the tips. At 30-40 cm depth in unlimed soils, Al was absent or questionably present (green fluorescence) with the greatest depositions occurring in the outermost mantle cells in spring and fall 1999, but the reverse was true in spring and fall 2000 with the heaviest accumulations in the Hartig net cells. At 50-60 cm depth, when Al was present in the mantle (spring 1999, fall 2000), it was absent from the Hartig net cells and when it was absent or questionable in the mantle, it was either absent (fall 1999) or modestly present (spring 2000) in the Hartig net.

In limed probes, the fungal cells were primarily Al-free at 0-10 cm depth with much less Al evident than in roots from unlimed soils. However, at 30-40 cm depth, the mantle cells strongly contained Al (with one exception-Spring 1999) and the corresponding Hartig net cells were mostly Al-free. The limed roots at 30-40 cm depth had a stronger Al presence than corresponding roots from unlimed soils. At 50-60 cm depth, the outer mantle cells, especially near the tips contained the most Al (Spring & Fall 1999) but at other times the concentrations were greater > 5 mm from the tip (Spring & Fall 2000). The outer Hartig net was frequently Al-free, but the inner Hartig net had some modest deposits (Spring 1999) or specks (Spring 2000) at this depth. Comparative Aluminum content between unlimed and limed probes from 50-60 cm depth could not be qualitatively determined.

Root Aluminum: In unlimed soils, the root cells were very variable in their Al content. The cortex varied considerably in Al content often with gradations in intensity sometimes varying from more intense near the endodermal barrier, to less frequently, the reverse, especially in the spring. Al was usually less intense < 1 mm from the tip at 0-10 cm depth, but more variable in deeper probes. In the spring less cortical Al was evident overall than in the fall at all depths. The phloem was Al -free except for fall 2000 at 50-60 cm depth. The pericycle and endodermis were also Al-free except for some suspiciously green cell walls at 0-10 cm depth in spring and fall 2000. In the deeper probes, Al was constantly present in the xylem, although varying in intensity but in shallow soil (0-10 cm) Al content was highly variable from being absent (Fall 2000, < 1 mm from tip) to variable (Spring & Fall 1999, Spring 2000) to being strongly present (Fall 1999 < 1 mm and Fall 2000 > 5 mm from tip). (Figure 12-25 H).

In limed soils, the root cells were very consistent in their Al content. The cortex always contained Al, frequently exhibiting gradation with the most intense deposits near the endodermal barrier. Aluminum was most strongly present close to the tip and at 0-10, and 30-40 cm depth, the probes were intensely and consistently yellow, while at 50-60 cm depth the cortical cells fluoresced orange, implying lower Al content. The pericycle and endodermal cells were Al-free except for suspiciously greenish cells at 0-10 cm depth in spring and fall 1999 (one year earlier than in the unlimed probes). The phloem was Al-free except for one sample (Spring 2000, 30-40 cm depth, > 5 mm from the tip). The xylem strongly and consistently contained Al at all depths and seasons (Figure 12-25F).

Summary: From the autofluorescence study, it is concluded that *Lactarius subdulcis* mycorrhizal roots produced an orange pigment during desiccation stress and that the limed roots produced the most pigmentation. The deposition of a green autofluorescent chemical seems to be age-related but not related to Aluminum sequestration or translocation or liming. The presence of chemical modifications induced in the root cell walls by the presence of the mycorrhiza *Lactarius subdulcis* may be related to its success, survival and elastic rebound after desiccation stress.

The sequestration of aluminum was the most prevalent, consistent and abundant in the limed mycorrhizae, the corresponding root cortex and xylem. In the unlimed mycorrhiza, regional sequestration (mantle vs Hartig net) was more apparent with the trends in aluminum uptake and storage being reversible depending upon soil moisture and seasonal microclimatic variations. At 0-10 cm depth, ability of the mantle of the unlimed roots to sequester Al meant less translocation and sequestration by the root cells while the limed roots had a lower mantle storage and greater translocation and sequestration by the root cells. At 30-40 cm, the limed mycorrhizal roots had more Al over all in all regions but at 50-60 cm depth, there was no relative difference between the unlimed and limed probes. In terms of total uptake, more Al was found in the limed mycorrhizal roots.

Figure 12-25A: ***Lactarius subdulcis*** **gross morphology.** The end of an irregularly pyramidal branched mycorrhizal system. Probe 300K from unlimed soil at 30-40 cm depth in spring 2000. 160x. Photo 3-2.

Figure 12-25B: ***Lactarius subdulcis*** **fine morphology.** The apex of a mycorrhizal system to show the smooth surface and range in color from pale golden yellow of young tips in comparison to the deeper golden color of older tips (Figure 12-25A). Probe 300K from unlimed soil at 30-40 cm depth in spring 2000. 260x. Photo 4-39.

Figure 12-25C: ***Lactarius subdulcis*** **autofluorescence < 1 mm from tip, unlimed.** The outer mantle and inner Hartig net is dull green while the inner mantle and outer Hartig net, sandwiched between is dull ochre. Some of the cortical cells fluoresce yellow or yellow-green. Probe 1000N from unlimed soil at 0-10 cm depth, fall 2000. Cx. 1000x. Photo 16-13, clear filter, 145 second exposure.

Figure 12-25D: ***Lactarius subdulcis*** **with Morin > 5 mm from tip, unlimed.** The fluorescence is very similar to autofluorescence but with one bright yellow spot (top left corner). Probe 1100N from unlimed soil at 0-10 cm depth, fall 2000. Cx. 1000x. Photo 16-17, clear filter, 90 second exposure, 5 minutes after treatment.

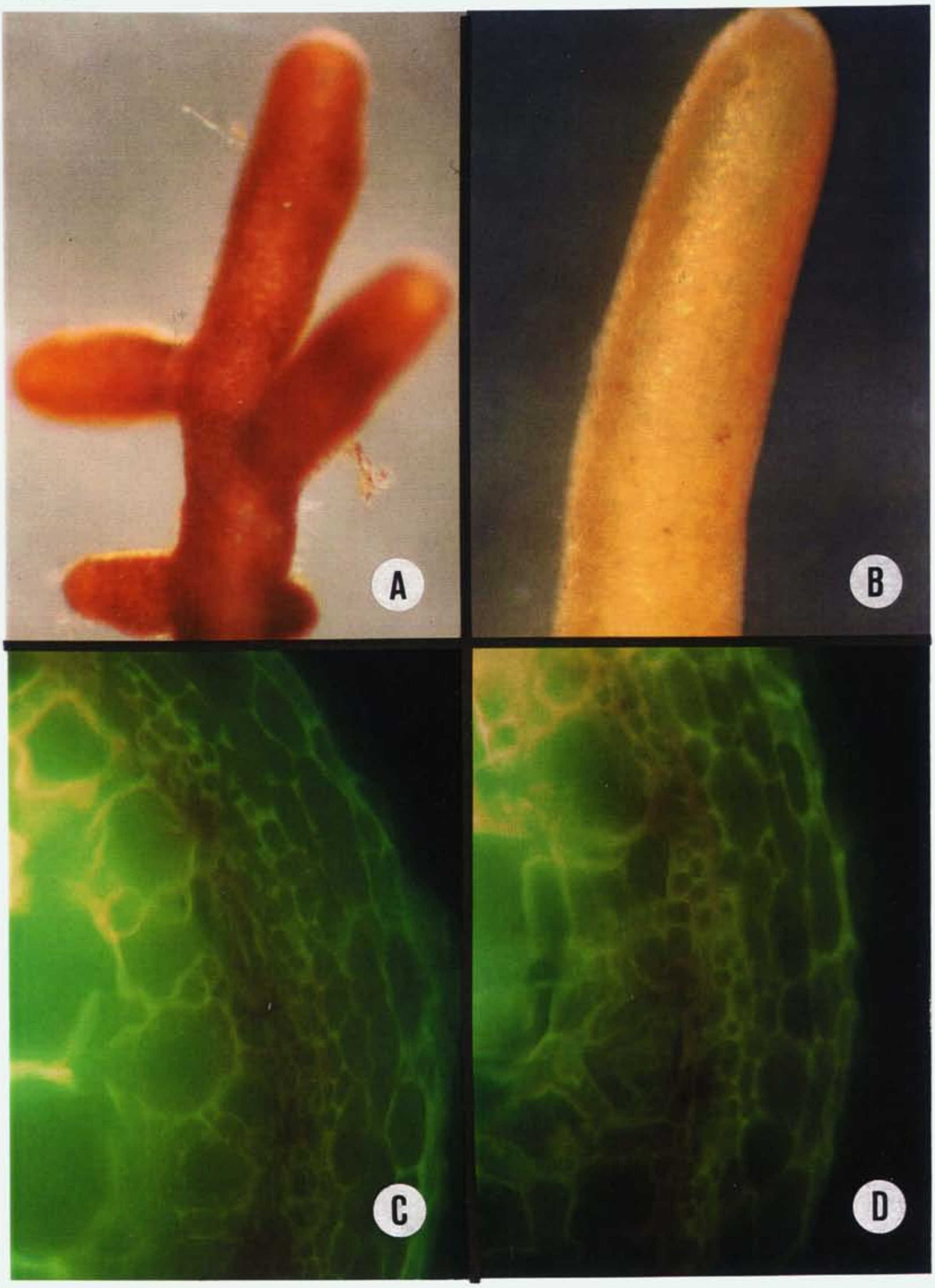
Figure 12-25E: ***Lactarius subdulcis*** **autofluorescence, < 1 mm from tip, limed.** The outer mantle is bright yellow, except at the very tip where it is more like the Hartig net area, bright to dull ochre. The cortical cells and the fragments of endodermis visible are blue to yellow-blue while the meristem cells are ochre to dull yellow. Probe 300K from limed soil at 30-40 cm depth in spring 2000. Lx. 400x. Photo 24-13, clear filter, 10 second exposure.

Figure 12-25F: ***Lactarius subdulcis*** **with Morin, < 1 mm from tip, limed.** In the rapid reaction, the mantle, cortical cells and xylem contain abundant aluminum while the endodermal cells which are poorly represented here, stayed blue. The meristem region only had modest Al. Probe 300K from limed soil at 30-40 cm depth in spring 2000. Lx. 250x. Photo 24-14, clear filter, 20 second exposure, 3 minutes after treatment.

Figure 12-25G: ***Lactarius subdulcis*** **autofluorescence, > 5 mm from tip, unlimed.** The outer fungal cells are thin, the Hartig net has collapsed and the fluorescence is very dull ochre-green in contrast to the bright blue-green of the cortex, and endodermis. The xylem is fainter blue-green. Probe 6NA from unlimed soil at 0-10 cm depth, spring 1999. Lx. 400x. Photo 24-20, clear filter, 60 second exposure.

Figure 12-25H: ***Lactarius subdulcis*** **with Morin, > 5 mm from tip, unlimed.** The outer mantle, cortex and xylem have strong aluminum content but the Hartig net, which is collapsed here only contains minimal Al and the phloem on either side of the long xylem strands is non-fluorescent while the endodermal cells are still blue. Probe 6NA from unlimed soil at 0-10 cm depth, spring 1999. Lx. 400x. Photo 24-22, clear filter, 60 second exposure, 11 minutes after treatment.

12-25



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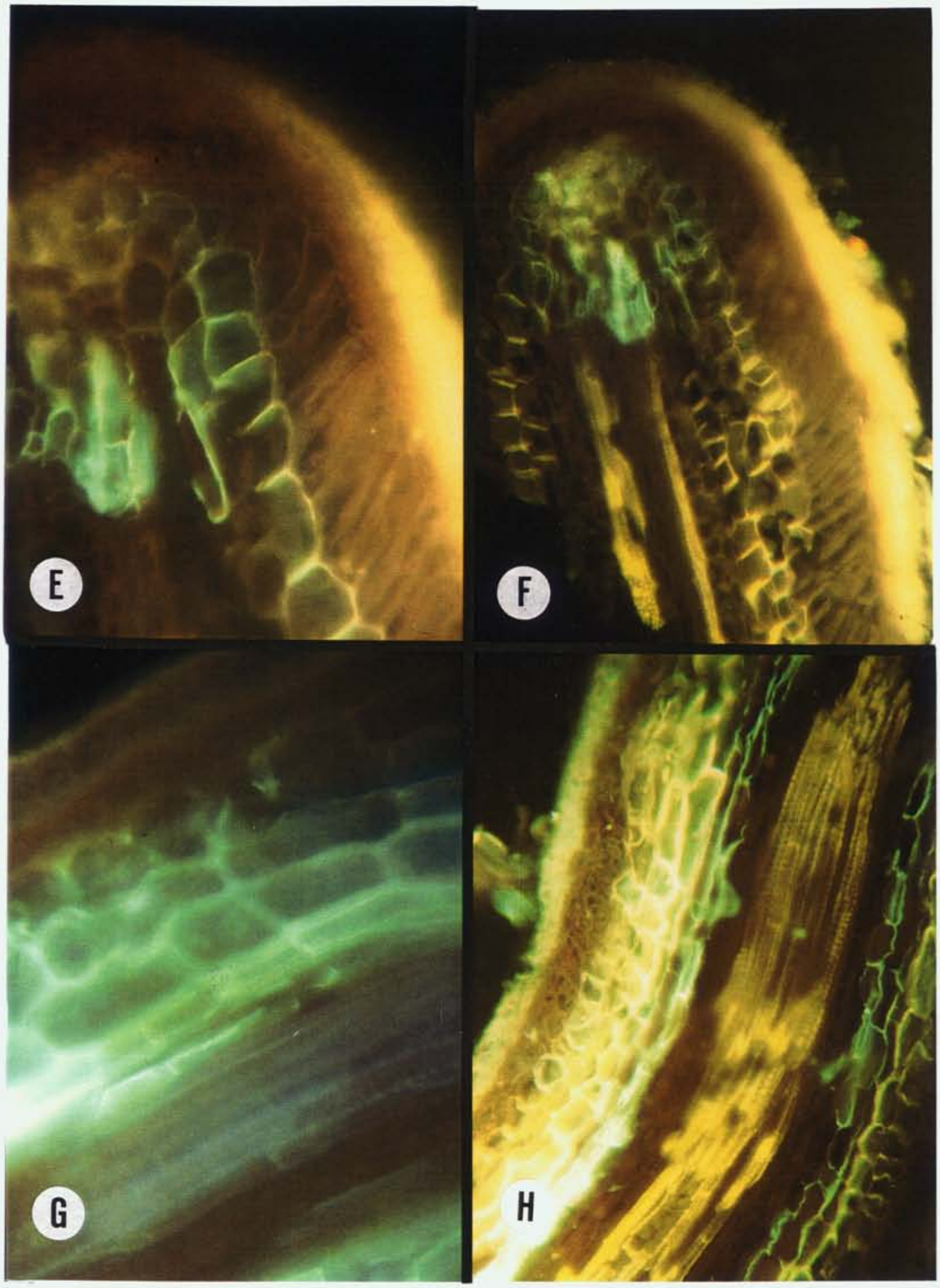

Appendix 12-26: Paxillus involutus

Fruiting body Occurrence: Fruiting bodies were very common in the fall 2000 in the unlimed forest zone but absent from the limed zone. Appendix 2C.

Mycorrhizal Occurrence: *Paxillus involutus* was very common in the unlimed soil at 0-10 cm depth and less abundant at 30-40 cm, except for fall 1999 during the drought when it dissappeared from most probes. It was rare in moist limed soil at 0-10 cm depth, but strongly present at 30-40 cm depth during the fall drought. It was rare or absent at 50-60 cm depth. (Appendices 7-26 and 8A-B3-33).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 27. Figure 12-26A, B.

Fungal Autofluorescence: In unlimed soil at 0-10 cm depth, the hyphae were faint orange (spring 2000) to faint orange-yellow (fall 2000) while at 30-40 and 50-60 cm depth they were faint yellow-green (fall 2000). The mycorrhizal mantle was similar except at 50-60 cm depth where it was yellow. The fungal cells in the Hartig net area at 0-10 cm depth were faint orange (spring 2000) to blue (fall 2000) while at 30-40 cm depth they were blue and at 50-60 cm depth they were orange (fall 2000) in unlimed soil (Figures 12-26 A, E). In limed soil, at 0-10 cm depth, the hyphae were faint yellow green (spring 2000) to non-fluorescent (fall 2000) while the cells of the Hartig net were faint orange (spring 2000) to faint orange-blue (fall 2000).

Root Autofluorescence: In the unlimed plots, the xylem, pericycle and endodermis were consistently blue. The phloem was non-fluorescent. The cortical cell walls varied from green (inner) to pale yellow (outer)(spring 2000) to blue (fall 2000) at 0-10 cm depth; blue at 30-40 cm depth and in outward gradation from blue to yellow at 50-60 cm depth (fall 2000) (Figures 12-26 A, E). In the limed plot, at 0-10 cm depth, the xylem was blue but the pericycle and endodermis were blue-green. The phloem was faint orange (spring 2000) to non-fluorescent (fall 2000). The cortical walls were yellow-blue (spring 2000) and blue-green (fall 2000). The presence of orange to yellow autofluorescence in cells that are normally blue may be a residual indicator of drought stress.

Fungal Aluminum: In unlimed soil, at 0-10 cm depth, the fungal cells were Al-free (spring 2000), but later (fall 2000) all the cells contained Al with the strongest concentration in the mantle. At 30-40 and 50-60 cm depths, the hyphae and mantle cells were Al-free but the Hartig net cells contained Al (Figures 12-26 D, F). In limed soil, at 0-10 cm depth, the hyphae and Hartig net cells were Al-free but the mantle cells contained Al (spring 2000), while later (fall 2000) a questionable amount of Al was present in the inner Hartig net area close to the root tip but further from the tip Al was found only in the outer mantle cells.

Root Aluminum: In unlimed soil, where Al was absent from the mantle, it was more concentrated in the xylem and cortical cells. In Spring 2000, at 0-10 cm depth Al was especially concentrated close to the tip but reduced in the cortex and sometimes absent from the xylem >5 mm distally. In Fall 2000, Al was faintly present in the Hartig net but extremely concentrated in the cortex (30-40 cm depth) but less so in the cortex at 50-60 cm depths, but the xylem concentrations were similar in both cases (Figures 12-26 D, F). In limed soil, Al was present in the xylem, cortex and mantle (spring 2000) and in the fall 2000 when it was absent to variable in the mantle it was somewhat more evident in the Hartig net but less evident in the xylem and cortex.

Summary: *Paxillus involutus* was more variable in its sequestration and translocation of aluminum in unlimed soil than in limed soil at 0-10 cm depth. In unlimed soil, when the mantle contained Al, less was present in the cortex and conversely, when Al was absent from the mantle and hyphae, it tended to accumulate in the Hartig net and especially strongly in the cortex. The highest cortical accumulations occurred at 30-40 cm depths. In limed soil, when Al was present in the mantle, less was evident in the Hartig net and cortical areas; and when Al was absent from the mantle close to the tip, slightly more Al accumulated internally. Overall, there was more Al in the unlimed roots, but this species was less successful in terms of biomass accumulation and distribution in limed soil.

Figure 12-26A: *Paxillus involutus* gross morphology. The mycorrhizae are tortuous, silvery (due to enclosed air) with typical reddish brown hyphae emanating and entwined into the mantle giving it an "aged" appearance. There are conspicuous branching central rhizomorphs surrounded by thinner ones. Probe 100N from unlimed soil at 0-10 cm depth in fall 1999. 110x. Photo 3-34.

Figure 12-26B: *Paxillus involutus* finer morphology. The brownish -red emanating hypha are clearly visible over the silvery mantle. Connections to the rhizomorphs are evident at the base of the top left mycorrhizal tip. Probe from unlimed soil, collected October 17, 2001. 320x. Photo 18-7.

Figure 12-26C: *Paxillus involutus* autofluorescence < 1 mm from tip. The irregularity of the outer (green to yellow-green) mantle is evident. The Hartig net is primarily dull orange (right) with some greener areas (left). The root is primarily blue although it appears blue-green here. Towards the bottom, an opening in the endodermis is visible and the xylem can be seen branching into the bifurcation area. Probe 1100N from unlimed soil at 50-60 cm depth in fall 2000. Cx. 400x. Photo 20-8, clear filter, 30 second exposure.

Figure 12-26D: *Paxillus involutus* with Morin < 1 mm from tip. The mantle is mostly aluminum free with the exception of the top right area. The Cortical cell walls contain variable amounts of Al, but the endodermis is unchanged. The xylem which can be seen on the bottom right where it is entering the bifurcation is intensely yellow. The phloem is present but non-fluorescent. Probe 1100N from unlimed soil at 50-60 cm depth in fall 2000. Cx. 400x. Photo 20-9, clear filter, 30 second exposure, 5 minutes after treatment.

Figure 12-26E: *Paxillus involutus* with Morin > 5 mm from tip, 5 min. The mantle is much thinner here and the Hartig net region has collapsed. The fungal areas are very dull blue-green while the cortical cells are blue, endodermal ring cells are intense blue as are the three central xylem regions. The phloem has a greenish-orange fluorescence. Probe 1NA from unlimed soil at 0-10 cm depth in spring 1999. Cx. 250x. Photo 5-20, green filter, 20 second exposure, 5 minutes after treatment.

Figure 12-26F: *Paxillus involutus* with Morin > 5 mm from tip, 10 min. The outer mantle and the inner cortex show signs of aluminum while the remaining cells are basically Al-free. 1NA from unlimed soil at 0-10 cm depth in spring 1999. Cx. 250x. Photo 5-21, green filter, 15 second exposure, 10 minutes after treatment. The reaction was not visible using the clear filter combination.

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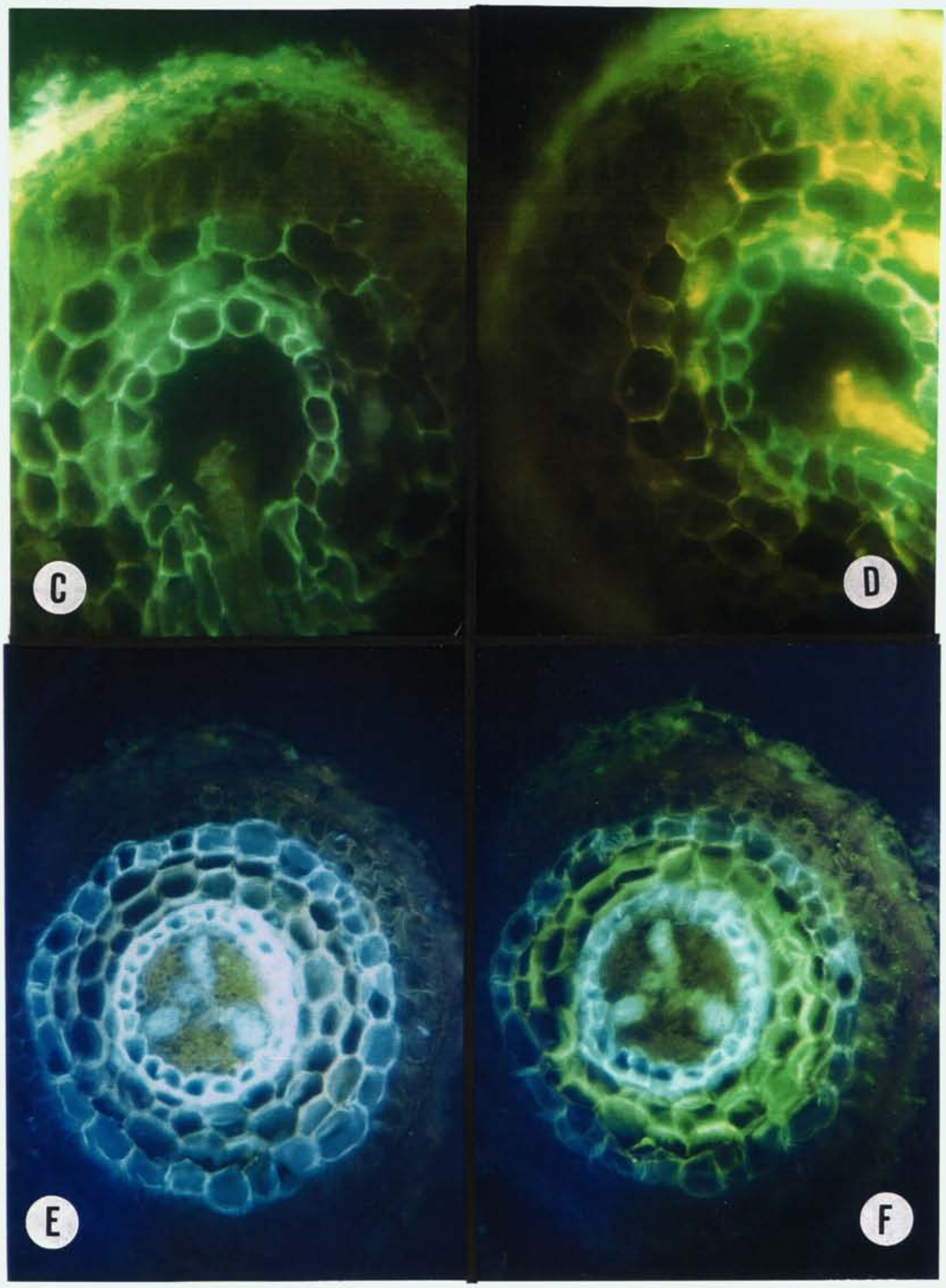


Appendix 12-27: Phellodon niger

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Phellodon niger* was common in unlimed moist soil at 0-10 cm depth, except for the dry fall 1999. It was present in moist limed soil at 0-10 cm depth fall 2000, otherwise it was rarely found (Appendices 7-27 and 8A-B3-34).

Mycorrhizal Morphology: Refer to Agerer (1987-1998), plate 78. This mycorrhiza was most easily recognized by its black spots visible under the mantle and near the base.

Fungal Autofluorescence: In both soils, the mantle cells fluoresced green while the outer Hartig net cells were pale (unlimed) to non-fluorescent (limed) and the inner Hartig net was primarily faint (unlimed) to deeper (limed) yellowish -orange. (Figure 12-27A).

Root Autofluorescence: In unlimed soil, the xylem was blue while the pericycle, endodermis and cortex were yellow-blue. In limed soil, the xylem, pericycle, endodermis and cortex were blue. The phloem was non-fluorescent in both and the hypoderm and epidermal cells shared the fungal fluorescence. Figure 12-27 A.

Fungal Aluminum: In unlimed soil, the mantle, but not the Hartig net contained Al. In limed soil, the mantle was Al-free but the Hartig net had Al present as bright green specks. Figure 12-27 B, C, D.

Root Aluminum: In unlimed soil, the xylem was Al-free to variable in its content and the cortex contained faint indications of Al presence. In limed soil, the xylem strongly contained Al in most areas while the cortex was moderate and variable in its content. The most aluminum appeared at the cortical-endodermal barrier. Figure 12-27 B, C, D.

Summary: In unlimed soil, Al was less readily observed in the xylem despite its poor storage in the Hartig net which implies that storage in the mantle was sufficient and translocation was minimal. In limed soil, Al was more readily translocated to the xylem despite its intensive storage in the Hartig net area

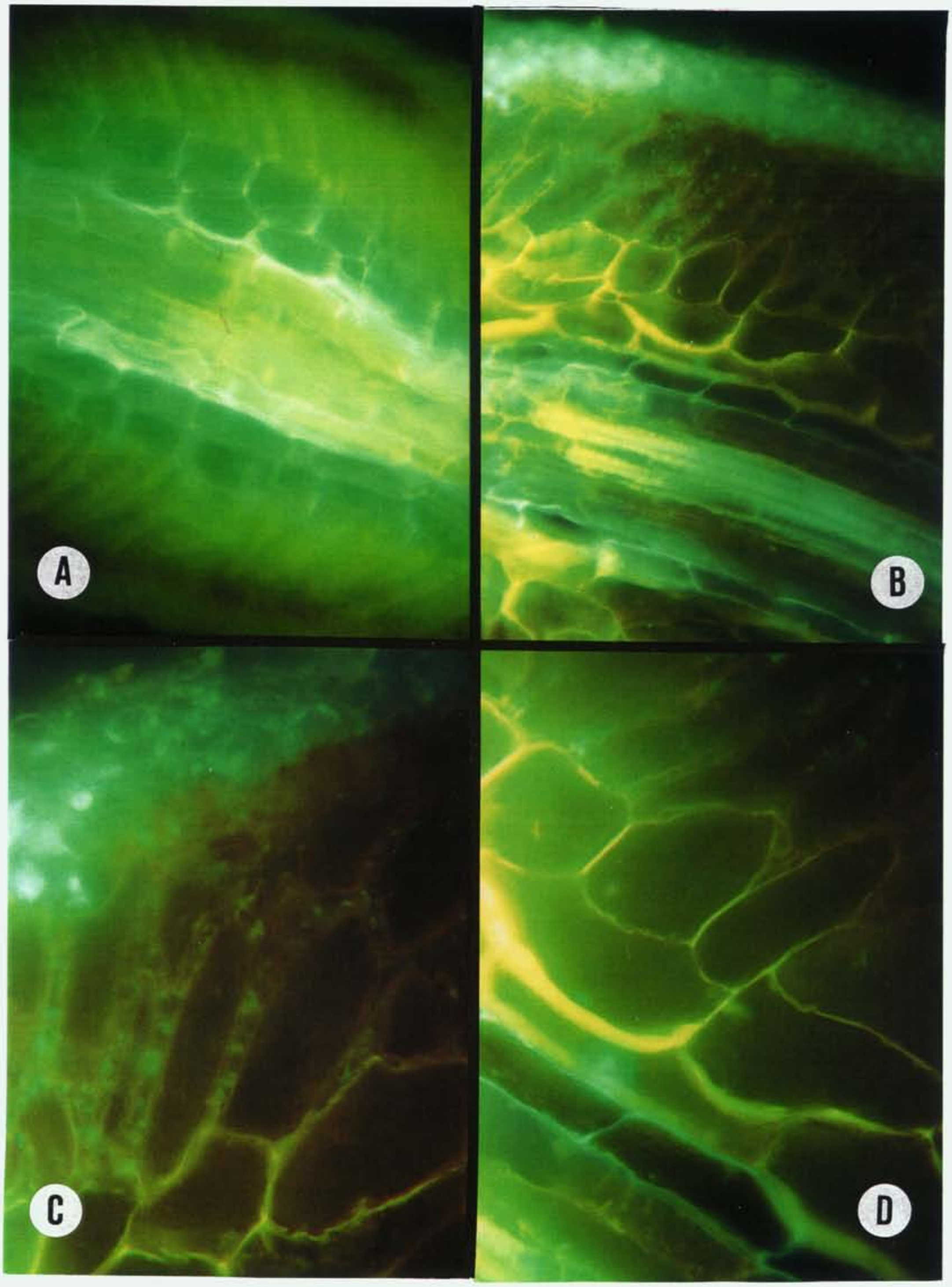
Figure 12-27A: *Phellodon niger* autofluorescence < 1 mm from tip. The mantle is faint green while the outer Hartig net is non-fluorescent and the inner Hartig net with its elongated cells is faint orange-yellow. The two layers of large square cortical cells is blue and the endodermis, which is only partly visible is bright blue while the xylem was bright yellow-blue in the central area. Probe 1000K from limed soil at 0-10 cm depth in spring 2000. Lx. 400x. Photo 23-6, clear filter, 60 second exposure.

Figure 12-27B: *Phellodon niger* with Morin < 1 mm from tip. While the mantle and Hartig net showed only tiny specks of Aluminum indicated by their brighter green fluorescence, the inner cortex was intense yellow in some areas, and in regions nearby, the xylem was also intense yellow but the endodermis and pericycle cells remained unaffected. Probe 1000K from limed soil at 0-10 cm depth in spring 2000. Lx. 400x. Photo 23-10, clear filter, 40 second exposure, 12 minutes after treatment.

Figure 12-27C: *Phellodon niger* with Morin, Mantle and Hartig net detail. The bright green specks are aluminum rich areas scattered in the mantle and Hartig net area. Their relative locations implies internal cytoplasmic sequestration rather than incorporation into the fungal walls. Probe 1000K from limed soil at 0-10 cm depth in spring 2000. Lx. 1000x. Photo 23-11, clear filter, 60 second exposure, 15 minutes after treatment.

Figure 12-27D: *Phellodon niger* with Morin, Cortex and Endodermis detail. The cortical cell walls show distinct aluminum (bright yellow) accumulation along the innermost walls while the long endodermal cells (lower left) have retained their blue autofluorescence. Probe 1000K from limed soil at 0-10 cm depth in spring 2000. Lx. 1000x. Photo 23-13, clear filter, 60 second exposure, 25 minutes after treatment.

12 - 27



Appendix 12-28: Piceirhiza bicolor

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Piceirhiza bicolor* was most common in unlimed soil at 0-10 cm depth in spring 2000, and during the moist fall 2000 it was found in low numbers also at 50-60 cm depth. It is possible that the deeper fall depth is an over-wintering strategy. In limed soil it was present only at 0-10 cm depth, fall 1999 and fall 2000. (Appendices 7-28 and 8A-B3-35).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 73. The tips were characteristically pale cream in direct contrast to less than a mm away where the hyphae are black. Many tips also have a constricted base. (Figure 12-28A).

Fungal Autofluorescence: In unlimed soil, at < 1 mm from the tip, the mantle cells were pale yellow (0-10 cm depth) to bluish-yellow (30-40 cm depth) to non-fluorescent (50-60 cm depth) and at > 5mm from the tip, primarily non-fluorescent. The Hartig net cells, when fully established, were pale bluish yellow (<1 mm) to more frequently pale orange (>1 mm).

In limed soil, at <1 mm from the tip, the mantle cells are pale yellow (spring 2000, 0-10 cm depth) to pale bluish-yellow (fall 2000, 0-10 cm and 50-60 cm depth) to pale orange (30-40 cm depth) and at > 5 mm from the tip vary from pale yellow (spring 2000, 0-10 cm depth) to non-fluorescent (fall 2000, 0-10 cm and 50-60 cm depth) to pale orange (30-40 cm depth). (Figure 12-28B).

Root Autofluorescence: In both unlimed and limed soil, the xylem, pericycle and endodermis are blue. The phloem was non-fluorescent except for the fall 2000, 50-60 cm depth probe from unlimed soil where it was faint orange. The cortical cells were usually blue except for one unlimed probe which was orange (Fall 2000, 0-10 cm depth) and two limed probes which were yellow-blue to yellow-green (Spring 2000, 0-10 and 30-40 cm depth). (Figure 12-28B).

Fungal Aluminum: In unlimed soil at 0-10 cm depth the mantle was Al-free while the Hartig net contained moderate amounts (Spring 2000) while in the fall of 2000 all the mantle cells contained intense amounts of Al. At 30-40 cm depth the mantle cells near the tip and all the Hartig net cells questionably contained Al traces while the mantle cells further from the tip were Al-free. At 50-60 cm depth the mantle cells and only the outer Hartig net questionably and variably contained traces of Al.

In limed soil, at 0-10 cm depth the fungal cells were Al-free (Spring 2000) and in the fall of 2000, only the mantle cells contained Al in the outermost hyphae. At 30-40 cm depth a few of the outer Hartig net cells had traces of Al while the mantle and the inner Hartig net cells were Al-free. (Figure 12-28C).

Root Aluminum: In unlimed soil, at 0-10 cm depth the xylem was Al-free (Spring 2000) to positive (Fall 2000) while the cortex was variable (Spring 2000) to positive (Fall 2000). At 30-40 cm depth the xylem was variable with faint traces of aluminum and the cortex had questionable traces. At 50-60 cm depth the xylem and cortex had small amounts of Al. In unlimed soil, in both the fungal cells and the root, the total amounts of Al declined with depth.

In limed soil, at 0-10 cm depth, the xylem and phloem both had more evidence of Al than the corresponding roots from unlimed soil despite the fact the fungal mantle was essentially Al-free. At 30-40 cm depth the xylem and cortex both strongly contained Al. (Figure 12-28C).

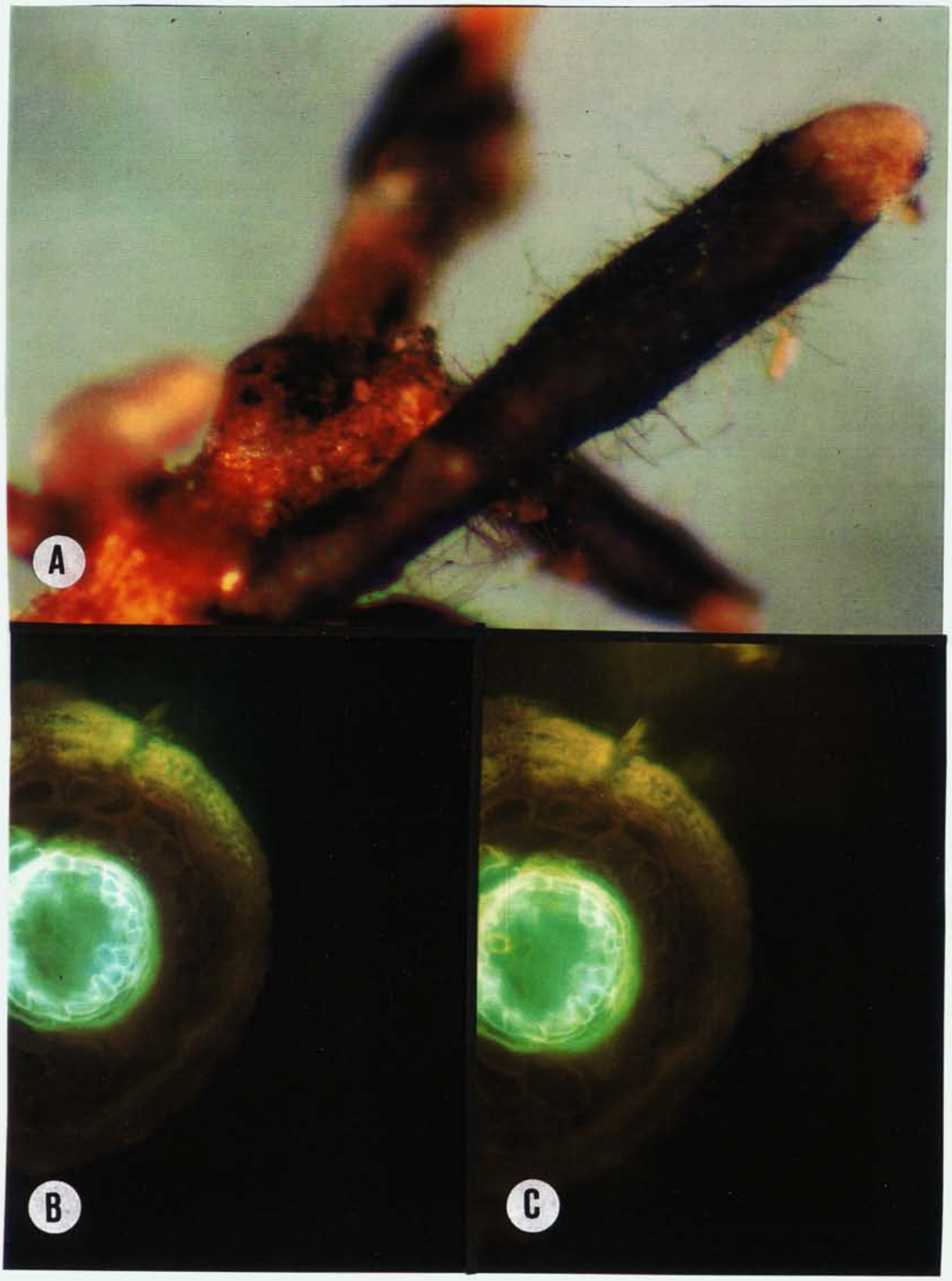
Summary: Unlimed mycorrhizae effectively sequestered or otherwise blocked in Al translocation to the xylem. In the limed samples *Piceirhiza bicolor* was less capable of sequestration allowing more Al to reach the xylem.

Figure 12-28A: *Piceirhiza bicolor* gross morphology. The simple ectomycorrhizae with whitish rounded tip and emanating black hyphae and narrowed base. Probe 100 N from unlimed soil at 0-10 cm depth, spring 2000. 300x. Photo 3-39.

Figure 12-28B: *Piceirhiza bicolor* autofluorescence < 1 mm from tip. The mantle is non-fluorescent to faint yellow-green and the minimal Hartig net is faint orange while the cortical cells and stele are bright blue. Probe 500K from limed soil at 30-40 cm depth, spring 2000. Cx. 400x. Photo 30-30, clear filter 30 second exposure.

Figure 12-28C: *Piceirhiza bicolor* with Morin < 1 mm from tip. There is a small amount of aluminum present in the cortical zone. Probe 500K from limed soil at 30-40 cm depth, spring 2000. Cx. 400x. Photo 30-31, clear filter, 15 second exposure, 5 minutes after treatment.

12- 28



Appendix 12-29: Piceirhiza chordata

Fruiting body Occurrence: None

Mycorrhizal Occurrence: In unlimed soil *Piceirhiza chordata,* found at all depths spring 1999, was almost completely absent during the dry fall 1999 but recovered the following spring with the strongest presence in fall 2000. It was most prevalent in 0-10 cm unlimed, moist soils. The same general trend was seen for limed probes except that the most abundant growth occured at 30-40 cm depth even during the drought. *Piceirhiza chordata* which disappears during times of drought stress, probably continues to persist as unrecognizable dry vegetative strands with strong recovery potential. (Appendices 7-29 and 8A-B36).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 28. This mycorrhiza was identifiable by its medium to light brown long old-looking tips. The thin mantle must be confirmed by microscopic section to differentiate mycorrhizal from non-mycorrhizal roots.

Fungal Autofluorescence: The thin mantle fluoresced variably appearing mostly yellowish-green or greenish-yellow. (Figures 12-29A to 12-29H). In unlimed soil the deeper mycorrhizae took on a slightly orange cast. The root epidermal and hypodermal cells in the potential Hartig net area, fluoresced faintly with an orange tint despite the absence of fungal strands. In unlimed roots in spring 1999 the mantle was yellow (0-10 cm depth) to orange (30-40 cm) to faint orange-yellow (50-60 cm). In spring 2000 it was yellow-green at all depths. In fall 2000 it was greenish-yellow (0-10 cm) and faint orange-yellow (30-40 cm).

In limed soil the mantle was more strongly green varying from yellow-green (spring 1999, all depths) to green-yellow (Fall 1999, 30-40 cm and 50-60 cm, Spring 2000, 0-10 cm). In the fall of 2000 there was considerably more variability in coloration. At 0-10 cm there was a gradation with the inner mantle being green and the outer hyphae faint yellow.

At 30-40 cm it was faint orange-yellow and at 50-60 cm the mantle near the tip was orange-green but further away faint orange-yellow.

Root Autofluorescence: The xylem, pericycle and endodermis fluoresced blue. (Figures 12-29A to 12029H). At 50-60 cm depth the pericycle and endodermis occasionally fluoresced blue-green (Spring 1999, unlimed; Fall 2000, limed). The cortex fluoresced faint blue to blue with a few exceptions: In unlimed soil it was yellow-green in one probe (Fall 2000,30-40 cm) and in limed soil it was green to blue to yellow-blue in one probe (Spring 1999, 50-60 cm). The phloem was normally non-fluorescent but occasionally faint orange (unlimed soil: Spring 1999, 30-40 cm and 50-60 cm; Spring 2000, 0-10 cm) (limed soil: Spring 1999, 50-60 cm, Fall 1999, 30-40 cm and 50-60 cm, Spring 2000, 0-10 cm; Fall 2000, 50-60 cm only at > 5 mm from the tip).

Even when there were no Hartig net cells in the epidermal and hypodermal regions they continue to fluoresce darkly with an orange tint, but occasionally lost the tint allowing the underlying blue fluorescence to show. In unlimed soil, the potential Hartig net area was primarily faint orange but close to the tips fluoresced blue (Spring 1999, 0-10 and 30-40 cm and Fall 2000, 0-10 cm) or faint orange yellow (Spring 1999, 50-60 cm). In limed soil, the potential Hartig net regions were orange in tint with the exception of fall 2000 when the cells > 5 mm from the tip were blue but only in roots from 30-40 and 50-60 cm depth.

Fungal Aluminum: In unlimed soil, at 0-10 cm depth the mantle cells were Al-free during the spring but not the fall. At 30-40 cm depth the mantle contained Al (Spring 1999) and was absent (Spring & Fall 2000). At 50-60 cm depth the mantle was Al-free which coincided with an increasingly orange natural fluorescence.

In limed soil, at 0-10 cm depth, the mantle cells all contained Al, but in Fall 2000 aluminum appeared mostly in the outermost hyphae. At 30-40 cm depth Al was present (Spring & Fall 1999) but absent (Fall 2000). AT 50-60 cm depth Al was absent (Spring 1999) but present (Fall 1999 & 2000) which coincided with a more intensely green-orange natural fluorescence. Liming definitely altered the aluminum retention processes resulting in more Al being sequestered by the fungi at all depths (Figures 12-29 B, D, F, H).

Root Aluminum: In unlimed soil, the xylem variably contained Al especially in the deeper probes while the phloem was Al-free. At 0-10 cm depth the pericycle occasionally contained specks (Spring 2000) and in one case there were heavy Al deposits outside the endodermal wall (Spring 1999) but otherwise these areas were Al-free. When the mantle was Al-free, more Al was present in the cortex along the diffusion gradient with the greatest concentrations near the endodermis (Spring 1999 & 2000, 0-10 cm) (Spring & Fall 2000, 30-40 cm). When aluminum was present in the mantle, more Al was evident in the potential Hartig net area and less in the cortex (Spring 1999, 30-40 cm) (Fall 2000, 0-10 cm). At 50-60 cm depth where the mantle was totally Al-free, the concentrations in the cortical areas were much more variable: In spring 1999 Al was found only in the outer cortical zone and in spring 2000 it was found in the same outer zone but also in the potential Hartig net area.

In limed soil, the xylem consistently contained aluminum except in some tips from 50-60 cm depth (Spring 1999). The phloem was Al-free except for on sample at 50-60 cm depth (Fall 1999). The pericycle and endodermis were Al-free except for one sample at 0-10 cm depth (Fall 2000) and another questionable probe at 50-60 cm depth (Spring 1999). The cortex contained Al at every depth and season with some Al-free regions in roots from 30-40 cm depth (Spring 1999) but other roots from this depth had strong deposits. The hypodermal and epidermal cell walls were weak in Al content at 0-10 cm and 50-60 cm but strong at 30-40 cm depths with more Al present in the fall samples than the spring samples. (Figures 12-29 B, D, F, H).

Summary: Mantle Aluminum was more strongly present in the limed probes than in the unlimed probes. Where Al was abundant in the mantle, it was less evident in the cortex and vica versa, where Al was less evident in the mantle, it accumulated along a gradient into the cortex. This pattern was less consistent in limed probes which generally contained more Al. In the unlimed probes, lower aluminum content was associated with increasingly orange autofluorescence. Limed probes tended to have a greener autofluorescence implying that whatever chemical was deposited in the unlimed samples was not as heavily or frequently deposited in the limed samples. The strongest cortical deposits tended to occur at 30-40 cm depth in both cases. Less Al was apparent in the xylem of the unlimed probes. The phloem in both cases remained relatively Al - free. Al was seemingly more readily translocated to the root cortex and xylem and more strongly sequestered in the limed probes.

Figure 12-29A: ***Piceirhiza chordata*** **autofluorescence < 1 mm from tip.** The outer mantle is faint green while the Hartig net is very faint orange and the root cells are blue with the endodermal cells being the most intense blue. Probe 1000K from limed soil at 30-40 cm depth, fall 2000. Cx. 400x. Photo 17-21, clear filter, 10 second exposure.

Figure 12-29B: ***Piceirhiza chordata*** **with Morin < 1 mm from tip.** The cortical and xylem cells show extremely strong yellow fluorescence indicating strong aluminum content. Probe 1000K from limed soil at 30-40 cm depth, fall 2000. Cx. 400x. Photo 17-30, clear filter, 15 second exposure, 20 minutes after treatment.

Figure 12-29C: ***Piceirhiza chordata*** **autofluorescence > 5 mm from tip.** The xylem (center) and some Hartig net cells (bottom right) autofluoresce yellow while the remaining cells are bright blue (endodermis & cortex) to green (mantle). Probe 1000K from limed soil at 30-40 cm depth, fall 2000. Lx. 400x. Photo 17-27, clear filter, 15 second exposure.

Figure 12-29D: ***Piceirhiza chordata*** **with Morin > 5 mm from tip.** The xylem shows clear indication of aluminum (brighter yellow at low magnification) as do some of the large cortical cells despite the initial yellow fluorescence. Probe 1000K from limed soil at 30-40 cm depth, fall 2000. Lx. 250x. Photo 17-28, clear filter, 15 second exposure, 5 minutes after treatment.

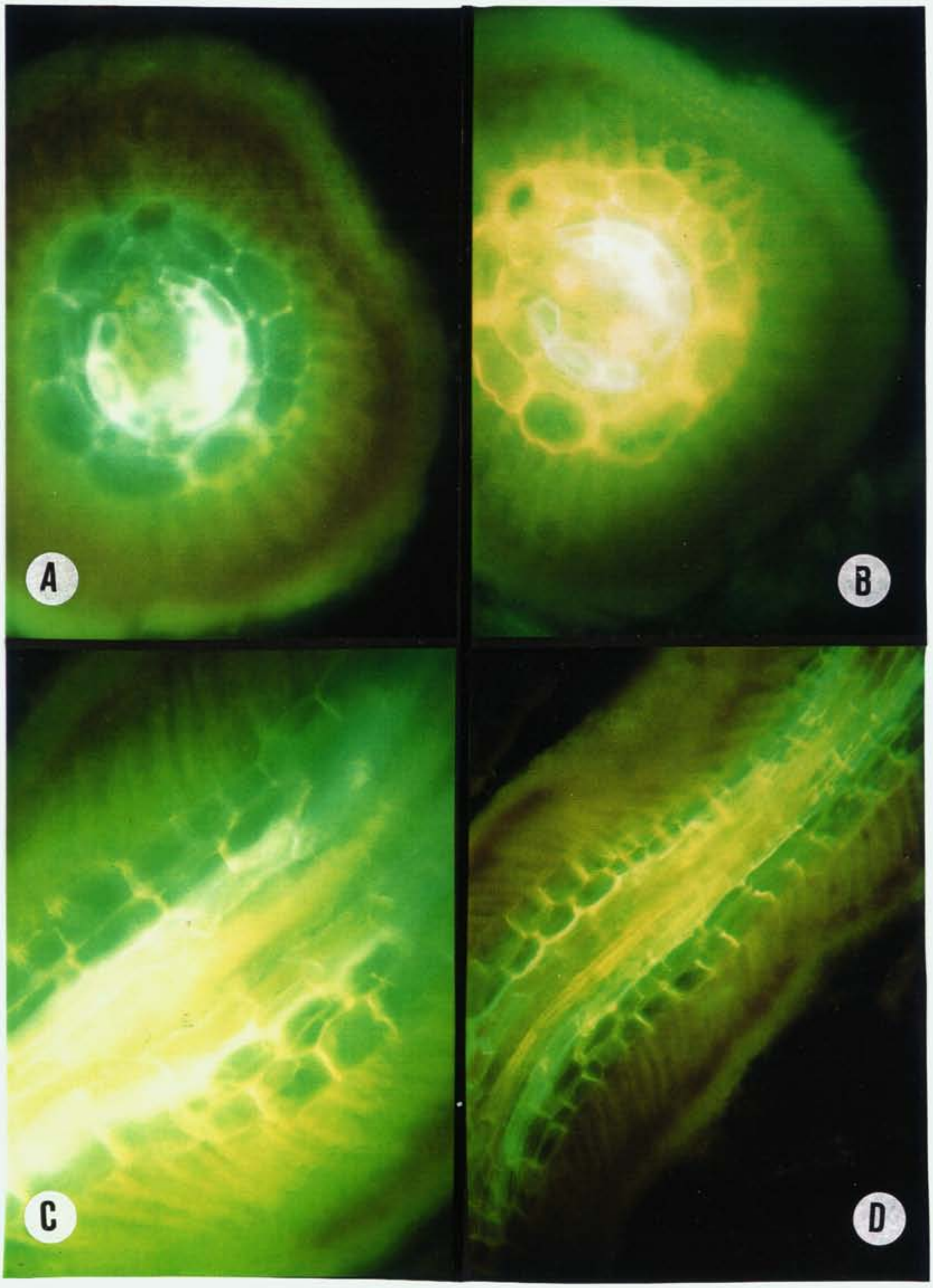
Figure 12-29E: ***Piceirhiza chordata*** **autofluorescence in ramification zone.** The thin mantle and Hartig net are dull to bright yellow in contrast to the blue root cells. Several regions of intense orange inclusions of unknown origin are present. Probe 1000K from limed soil at 30-40 cm depth in fall 2000. Lx. 250x. Photo 17-19, clear filter, 60 second exposure.

Figure 12-29F: ***Piceirhiza chordata*** **with Morin in ramification zone.** The cortical cells and xylem have strong evidence of Aluminum especially near the branching junction. Probe 1000K from limed soil at 30-40 cm depth in fall 2000. Lx. 250x. Photo 17-23, clear filter, 60 second exposure, 5 minutes after treatment.

Figure 12-29G: ***Piceirhiza chordata*** **autofluorescence in combined zones.** The region shows shared mycorrhizal mantles between old and new tips. The outer mantle is yellow-green and the Hartig net is faint orange. The root cells fluoresce blue. To the right is a large central cylinder with well developed pericycle cell layers. Probe 1K from limed soil at 0-5 cm depth in spring 1999. Lx. 250x. Photo 7-13, green filter, 30 second exposure.

Figure 12-29H: ***Piceirhiza chordata*** **with Morin in combined zones.** The aluminum is limited to the new mycorrhizal tip and the cortical cells connecting to the older root areas. Probe 1K from limed soil at 0-5 cm depth in spring 1999. Lx. 250x. Photo 7-15, green filter, 25 second exposure, 5 minutes after treatment.

12 - 29



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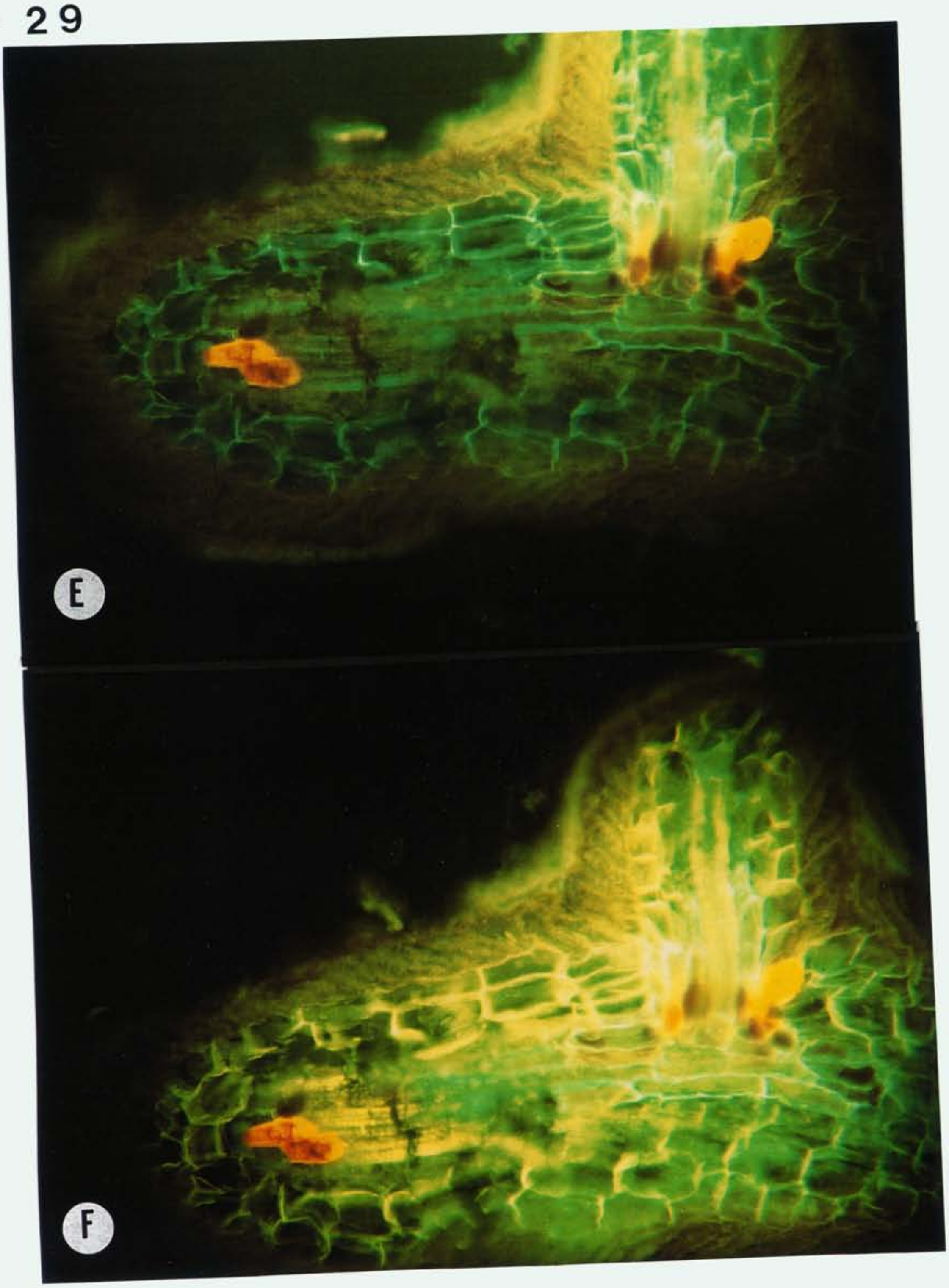
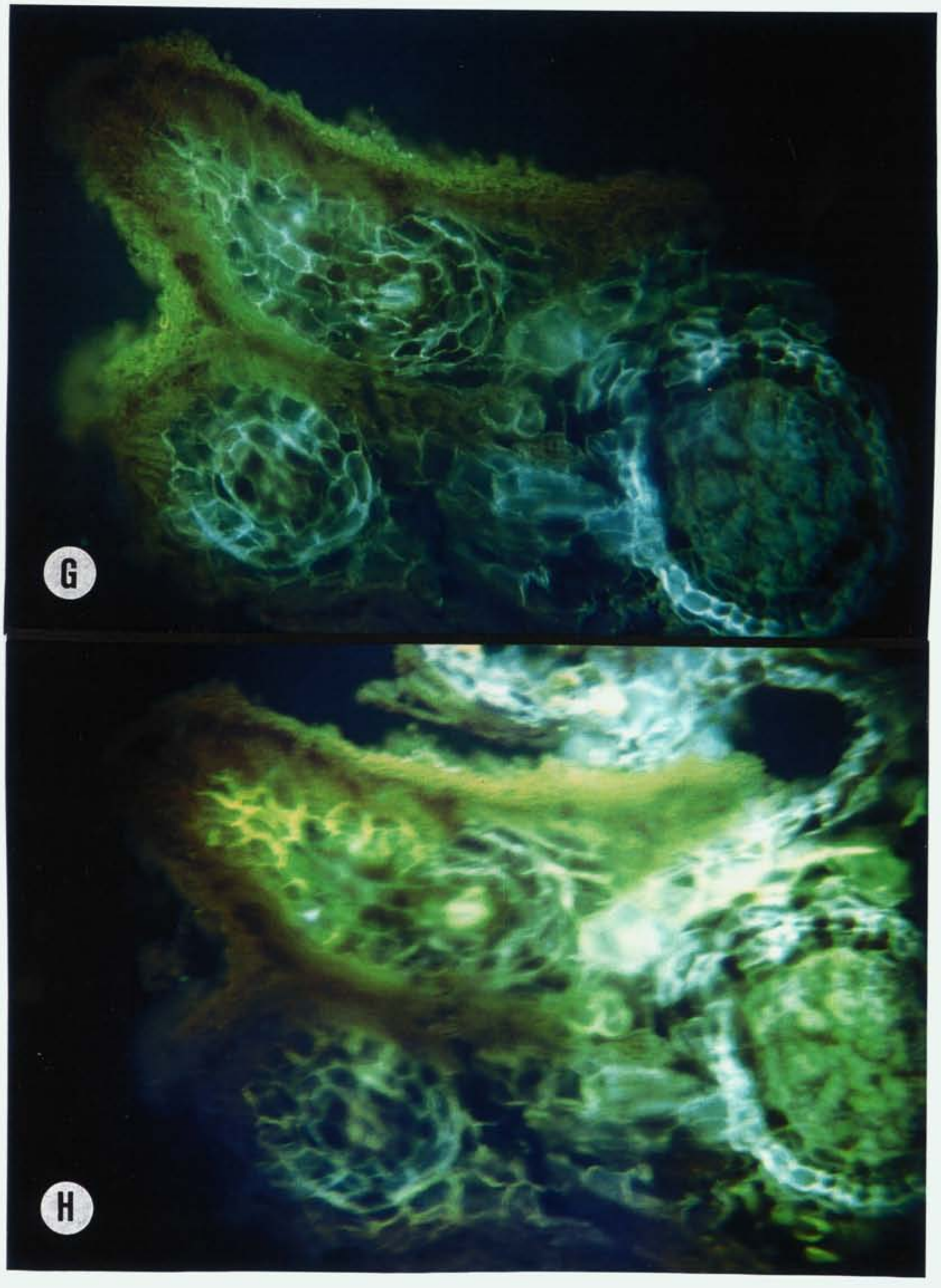


12 - 29



Appendix 12-30: Picerihiza gelatinosa

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Piceirhiza gelatinosa* was rarely isolated from limed soils. In moist unlimed soils it was most common at 0-10 cm depth in the spring of 2000 and less frequent at 30-40 cm depth spring and fall 2000 (Appendices 7-30 and 8A-B3-37).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 30. (Figure 12-30A).

Fungal Autofluorescence: In both unlimed and limed samples, the mantle fluoresced faint yellow while the Hartig net cells, which penetrated only into the epidermal layer, were faint orange (unlimed) to faint yellow (limed). (Figure 12-30B).

Root Autofluorescence: Typical. (Figure 12-30B). The phloem was non-fluorescent in the unlimed probes but faint orange in the limed probes.

Fungal Aluminum: Aluminum was moderately present in the mantle cells in both cases. In the unlimed roots however it was evident in the hypodermal net area (not epidermal layer area) while in limed roots Al was present in the epidermal region but only questionably so in the hypodermal region. (Figure 12-30C)

Root Aluminum: Aluminum was present in the cortex and xylem of the unlimed probes but questionable or absent in the limed probes. (Figure 12-30C).

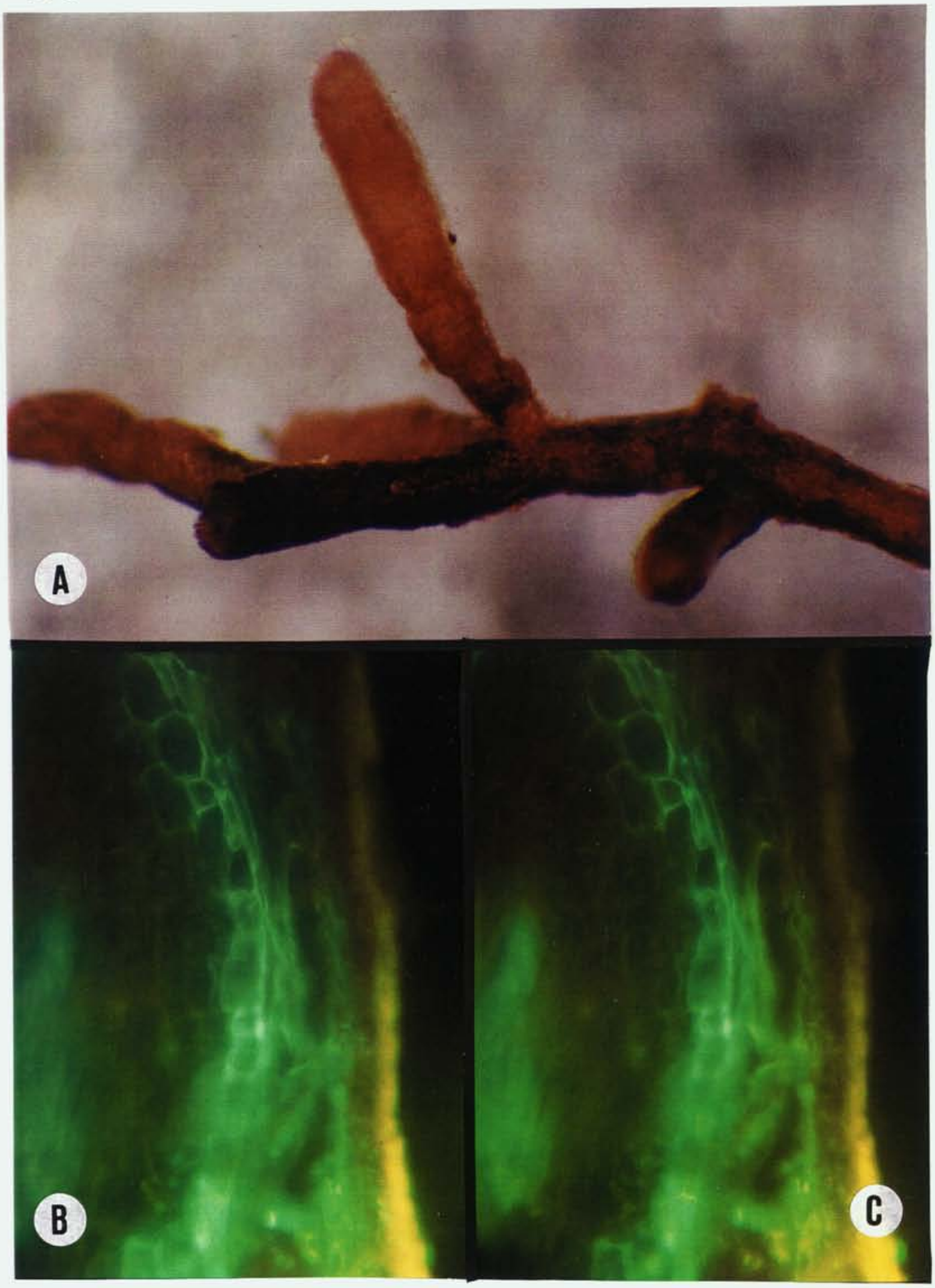
Summary: Overall, Al was present in the occasionally present in the mantle but generally more common in unlimed root walls and absent from the limed root walls of this rare mycorrhizal species.

Figure 12-30 A: *Piceirhiza gelatinosa* gross morphology. The unramified mycorrhizae have a pale apex with yellow-ochre body and darker, constricted, bases. Probe 300N from unlimed soil at 0-10 cm depth, spring 2000. 250x. Photo 5-21.

Figure 12-30 B: *Piceirhiza gelatinosa* autofluorescence > 5 mm from tip. The mantle is bright to faint yellow. Probe 200K from limed soil at 0-10 cm depth in spring 2000. Lx. 400x. Photo 31-24, clear filter, 30 second exposure.

Figure 12-30 C: *Piceirhiza gelatinosa* with Morin > 5 mm from tip. No aluminum is evident. Probe 200K from limed soil at 0-10 cm depth in spring 2000. Lx. 400x. Photo 31-25, clear filter, 30 second exposure, 5 minutes after treatment.

12 - 30



Appendix 12-31: Piceirhiza glutinosa = Elaphomyces sp.

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Piceirhiza glutinosa* was strongly present in fall 2000 from 0-10 cm depth in both unlimed and limed moist soils. In unlimed soil it was present in spring 1999 at 30-40 cm depth and in spring 2000 at 0-10 cm depth, but in limed soil it was present in spring 1999 at 0-10 cm depth and in spring 2000 at 30-40 cm depth (Appendices 7-31 and 8A-B3-38). The physiology for the depth reversals in spring is unclear probably related to long-term differential adaptation to liming and acidification.

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 31. (Figure 12-31A).

Fungal Autofluorescence: The mantle cells at 0-10 cm depth fluoresced faint yellow in both cases. In unlimed soil at 30-40 cm depth, the outer mantle was fainter bluish yellow. The Hartig net varied from blue to orange blue to bluish yellow. (Figure 12-31B)

Root Autofluorescence: Typical. (Figure 12-31B)

Fungal Aluminum: At 0-10 cm depth, Al was questionably present in the outer mantle and present only as specks in the Hartig net areas in both cases. At 30-40 cm depth in unlimed soil, Al was faintly present in the Hartig net area but more strongly present in the outer mantle. (Figure 12-31C).

Root Aluminum: In unlimed soil at 0-10 cm depth, Al was faintly present in the xylem, and variable in the cortex with more evident in the outer regions. In limed soil, Al was strongly present in the xylem, and variable in the cortex but with more evident in the inner regions near the endodermis. At 30-40 cm depth in unlimed soil, Al was present throughout the cortex, somewhat evident in the Hartig net area and strongly present in the mantle but the xylem was very variable in its content. (Figure 12-31C).

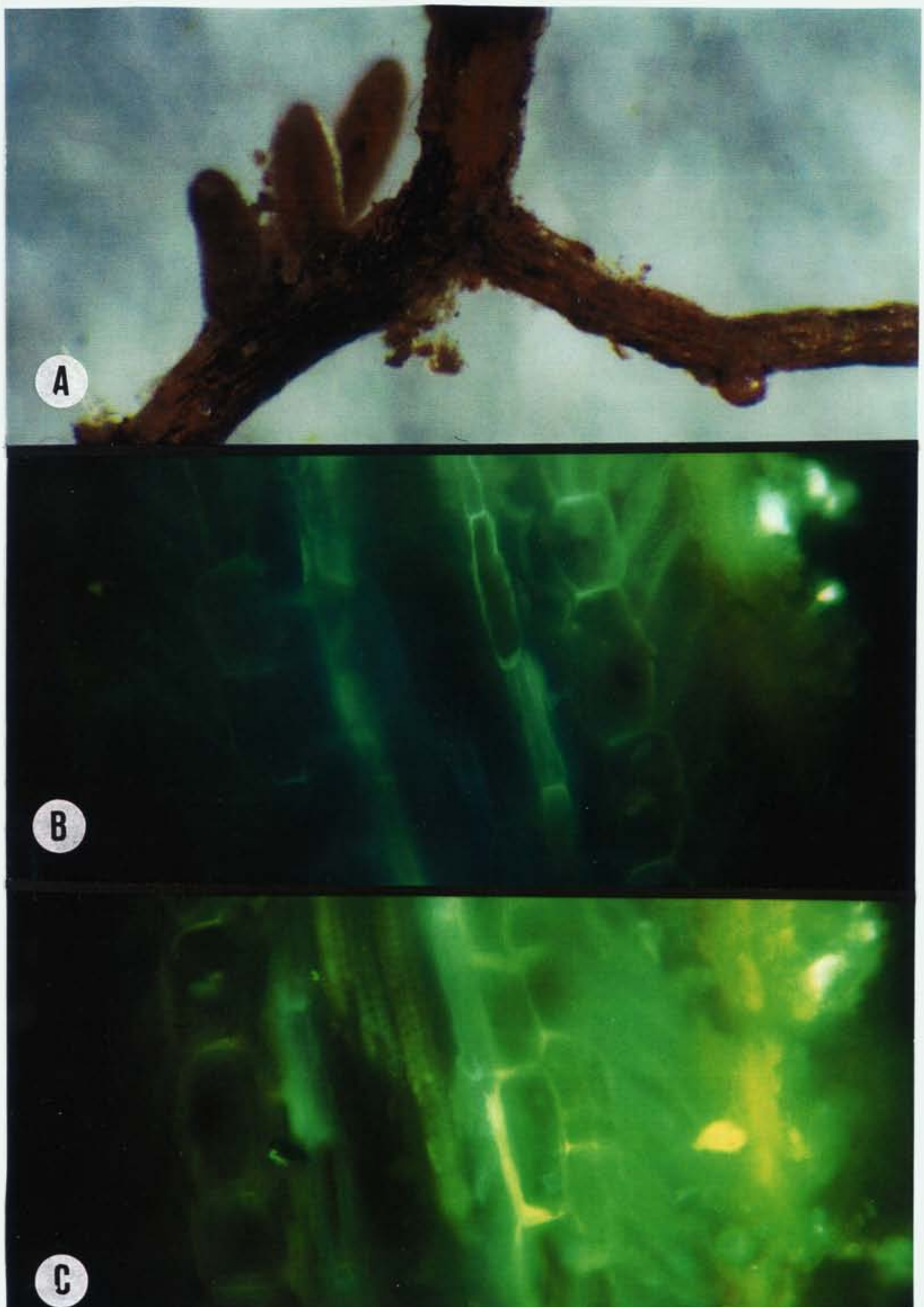
Summary: Aluminum seemed to move more readily into the root in the limed probes from 0-10 cm depth where it was also slightly more evident in the fungal sheath. In unlimed soil, more Al is present in the mantle at 30-40 cm depth than 0-10 cm depth.

Figure 12-31A: ***Piceirhiza glutinosa*** **gross morphology.** Three very young tips shown with a new tip emerging. Probe 400N from unlimed soil 0-10 cm depth, spring 2000. 250x. Photo 7-6.

Figure 12-31B: ***Piceirhiza glutinosa*** **autofluorescence > 5 mm from tip.** The mantle (right side of photo) is non-fluorescent to green, while the large cortical and elongated endodermal cells are blue-green and the xylem is non-fluorescent. Probe 1600 NB from unlimed soil at 0-10 cm depth n fall 2000. Lx. 400x. Photo 31-18, clear filter, 30 second exposure.

Figure 12-31C: ***Piceirhiza glutinosa*** **with Morin > 5 mm from tip.** The mantle is more clearly evident now and strongly contains aluminum. The xylem which was non-fluorescent in the above photo is now visible as three tubes just left of the center of the photo. Some aluminum was also present in the inner walls of the cortical cells. Probe 1600 NB from unlimed soil at 0-10 cm depth n fall 2000. Lx. 400x. Photo 31-20, clear filter, 30 second exposure, 12 minutes after treatment.

12 - 31



Appendix 12-32: Piceirhiza guttata

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Piceirhiza guttata* was rarely found. During the drought (fall 1999 it was present in limed soils at all depths, but absent or rare in unlimed. After the dry spell, it was strongly present in unlimed soil at 0-10 cm depth in spring 2000 but had a delayed appearance in limed soil at 0-10 cm depth until fall 2000. (Appendices 7-32 and 8A-B3-39).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 32. (Figure 12-32C).

Fungal Autofluorescence: In both unlimed and limed probes, the outer mantle cells fluoresced faint yellow-green while the Hartig net cells were faint orange. (Figure 12-32A)

Root Autofluorescence: In both cases, the xylem, pericycle and endodermis were blue while the epidermal and hypodermal cells matched the invading fungal hyphae and fluoresced faint orange. In unlimed soil, the cortex fluoresced blue-green and the phloem was faint yellow. In limed soil, the cortex was faint yellow and the phloem was non-fluorescent. (Figure 12-32A).

Fungal Aluminum: Aluminum was questionably present as specks in the unlimed mantle while the limed probes were primarily Al-free. (Figure 12-32B).

Root Aluminum: Aluminum was weakly present in the xylem and cortex of the unlimed probes but strongly present in the cortex and xylem in the limed probes. The phloem of the unlimed probes had some Al present in the walls.

Summary: In this rare species, it seems that Al was more readily stored in the cortex and xylem in the limed probes and not stored in the fungal cells. In the unlimed probes, more Al bypassed the root storage areas and was translocated (if we assume that deposition in the phloem occurs after the aluminum has been translocated to the leaves and back). The ability of the mycorrhizal root to sequester Al may determine the amount that is effectively translocated to the leaves.

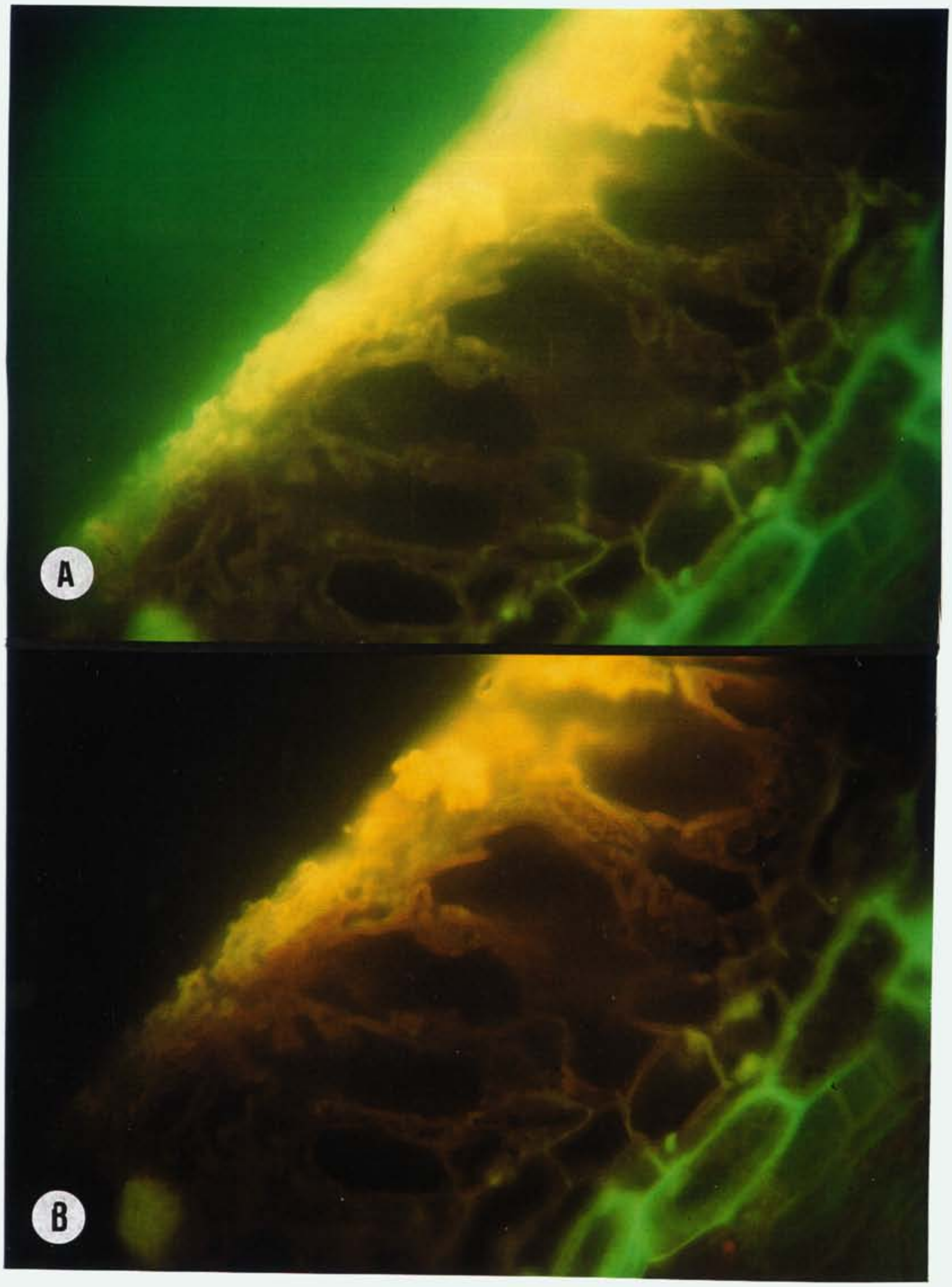
Figure 12-32A: *Piceirhiza guttata* autofluorescence > 5 mm from tip. The thin mantle fluoresces yellow while the Hartig net is dull orange and the cortical cells bright green. Probe 6KA from limed soil at 30-40 cm depth. Lx. 1000x. Photo 12-6, clear filter, 60 second exposure.

Figure 12-32B: *Piceirhiza guttatta* with Morin > 5 mm from tip. The mantle and Hartig net have some evidence of aluminum (deeper yellow). Probe 6KA from limed soil at 30-40 cm depth. Lx. 1000x. Photo 12-6, clear filter, 60 second exposure, 10 minutes after treatment.

Figure 12-32C: *Piceirhiza guttata* gross morphology. Soil particles adhering to gelatinous matrix surface. Irregular monopodal-pinnate system with typical paler tipped apices. Probe 400N from unlimed soil at 0-10 cm depth, spring 2000. 200x. Photo 7-11.

Figure 12-32D: *Piceirhiza nigra* gross morphology. Monopodal-pinnate mycorrhizal system with a few emanating hyphae. Probe 200K from limed soil at 30-40 cm depth, spring 2000. 75x. Photo 4-22.

12- 32



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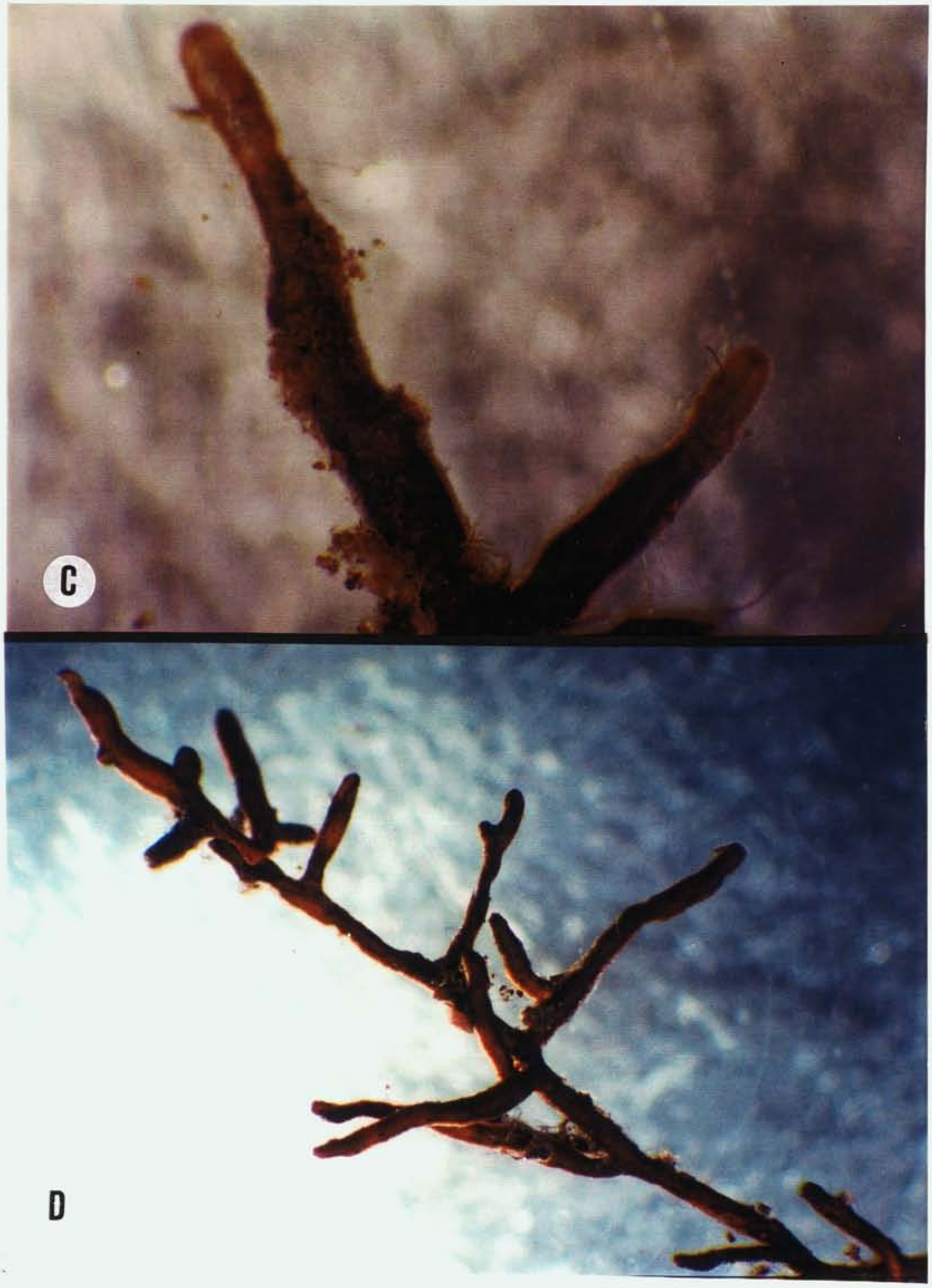


Appendix 12-33: Piceirhiza nigra

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Very common. *Piceirhiza nigra* was most common at 0-10 cm depth especially in the spring 1999 (limed) and spring 2000 (unlimed) and fall 2000 (both). In the spring 1999, it was also isolated, but to a lesser extent from 30-40 cm and 50-60 cm depths in unlimed probes, but war rare in the limed probes. It was nearly completely absent from all probes during the fall 1999 dry spell (Appendices 7-33 and 8A-B3-40).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 19. Long, dark brown to black grainy mycorrhizae in a monopodial-pinnate system. Under fluorescence examination, heaps of roundish cells gave the outer mantle an irregular margin. (Figures 12-33A, 33B, 33E, 33F, 33G) (Figure 12-32D).

Fungal Autofluorescence: Where the emanating hyphae were present, they fluoresced faint yellow in all cases. The outer mantle cells were more variable with usually the outermost cells fluorescing faint yellow, while the inner cells were non-fluorescent. Occasionally the entire outer mantle tended to be faint yellow. The Hartig net cells were primarily faint orange with the underlying blue of the epidermal and hypodermal cells sometimes showing through. (Figures 12-33A, 33E)

Root Autofluorescence: The root cells exhibited typical autofluorescence (Xylem, pericycle, endodermis, cortex = blue, phloem = non-fluorescent, hypodermis & epidermis = matching the fungal cells) with one exception. In the spring 1999, in the unlimed probes from 0-10 cm depth, the phloem and endodermal walls were faint yellow while the hypodermal and epidermal cells were all blue. (Figures 12-33A, 33C, 33E)

Fungal Aluminum: At 0-10 cm depth, in the unlimed probes, the hyphae all contained Al as did the outer regions of the outer mantles, but the Hartig net was Al-free. At 0-10 cm depth, in the limed probes, the hyphae were Al-free while the outer mantle was more uniform in its Al content and the Hartig net was Al-free in the spring but not the fall samples. In the limed probes, the entire mantle was Al-free in spring 2000. Aluminum seemed to be more common in the spring in the unlimed probes and conversely, more common in the fall in the limed probes at 0-10 cm depth. At 30-40 cm depth in both the unlimed and limed probes, the mantles at < 1 mm from the tips were Al-free while at > 5 mm from the tips the unlimed probes contained Al in the outer mantle and the limed probes had possible specks in the Hartig net. At 50-60 cm depth in the limed samples, Al was present in the mantle but not the Hartig net. (Figures 12-33B, 33F, 33G).

Root Aluminum: At 0-10 cm depth Al was variably present in the xylem and cortical cell walls. The only evident pattern in both cases was that if the Al was more concentrated in the mantle, it was less evident in the root walls and vica versa. The cortical accumulations tended to be stronger in the fall in the unlimed probes but were still very variable in the limed probes. At 30-40 cm depth, the samples were more consistent in their color distribution but the limed probes had slightly greater Al accumulation in the cortical and xylem walls. At 50-60 cm depth in the limed samples, Al was present in the cortex and xylem. (Figures 12-33B, 33D, 33F, 33G).

Summary: At 0-10 cm it was difficult to distinguish which probes had more aluminum content. Both were variable in uptake but very generally the unlimed probes tended to have more Al in their mantles in spring, while the limed probes tended to have stronger fluorescences in the fall. The other pattern that became evident was that if the Al content of the mantle was high, that of the cortex was usually lower and vica versa. At 30-40 and 50-60 cm depth, this species was more common in limed soil, but also had more evident aluminum accumulation in the root cells. Liming seems to have affected some basic seasonal physiology in this species with intense variability in individual tips existing regardless of location. Interestingly the variability disappears at 30-40 cm depth where this species has identical uptake patterns regardless of liming.

Figure 12-33A: *Piceirhiza nigra* autofluorescence > 5 mm from tip. The outer mantle varied from pale to bright yellow in fluorescence but the inner region of collapsed Hartig net was non-fluorescent to faint orange-yellow. The Root cells were blue to blue-green except for the non-fluorescent phloem. Probe 900K from limed soil at 0-10 cm depth, fall 2000. Cx. 400x. Photo 29-20, clear filter, 15 second exposure.

Figure 12-33B: *Piceirhiza nigra* with Morin > 5 mm from tip. There was no evidence of aluminum except for a slightly brighter xylem. Probe 900K from limed soil at 0-10 cm depth, fall 2000. Cx. 400x. Photo 29-22, clear filter, 15 second exposure, 15 minutes after treatment.

Figure 12-33C: *Piceirhiza nigra* autofluorescence > 5 mm, stele. The central xylem tubes fluoresced yellow to blue in this section as did the elongated cells of the endodermis on either side, while the large cortical cells lateral to the endodermis were blue. Probe 400K from limed soil at 0-10 cm depth, spring 2000. Lx. 250x. Photo 29-3, clear filter, 90 second exposure.

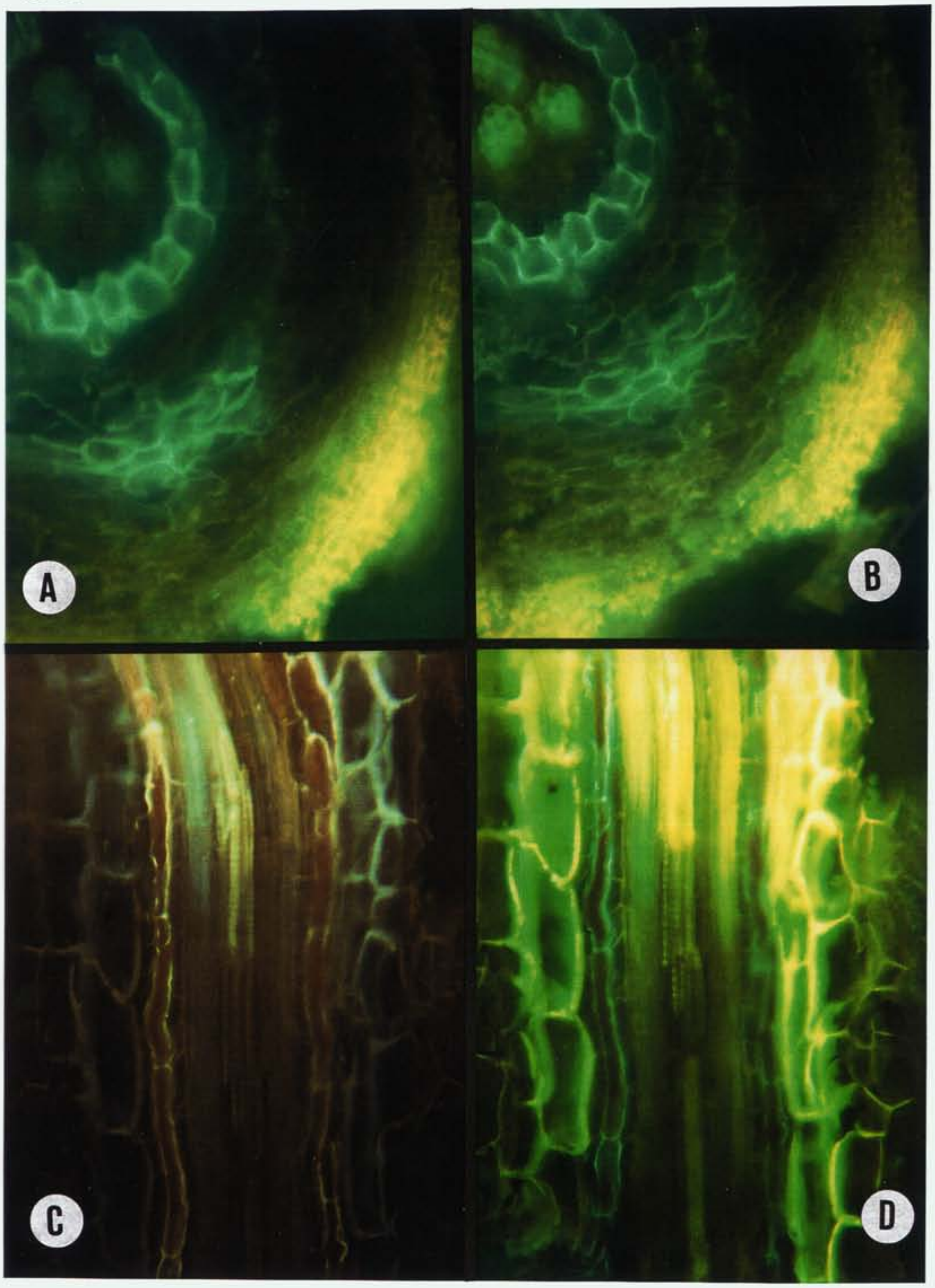
Figure 12-33D: *Piceirhiza nigra* with Morin, > 5 mm, stele. The central xylem tubes and the lateral cortical cells both show intense aluminum deposition while the sandwiched endodermal cells remained blue. Probe 400K from limed soil at 0-10 cm depth, spring 2000. Lx. 250x. Photo 30-10, clear filter, 60 second exposure, 25 minutes after treatment.

Figure 12-33E: *Piceirhiza nigra* autofluorescence < 1 mm from tip. The outer mantle has much adhering debris. The outer mantle varied from non-fluorescent to bright yellow while the well formed Hartig net region was non-fluorescent in the outer areas and faint orange-green in the inner areas. The remaining root cells were primarily bright blue. Probe 1K from limed soil at 5-10 cm depth, spring 1999. Cx. 250x. Photo 29-7, clear filter, 30 second exposure.

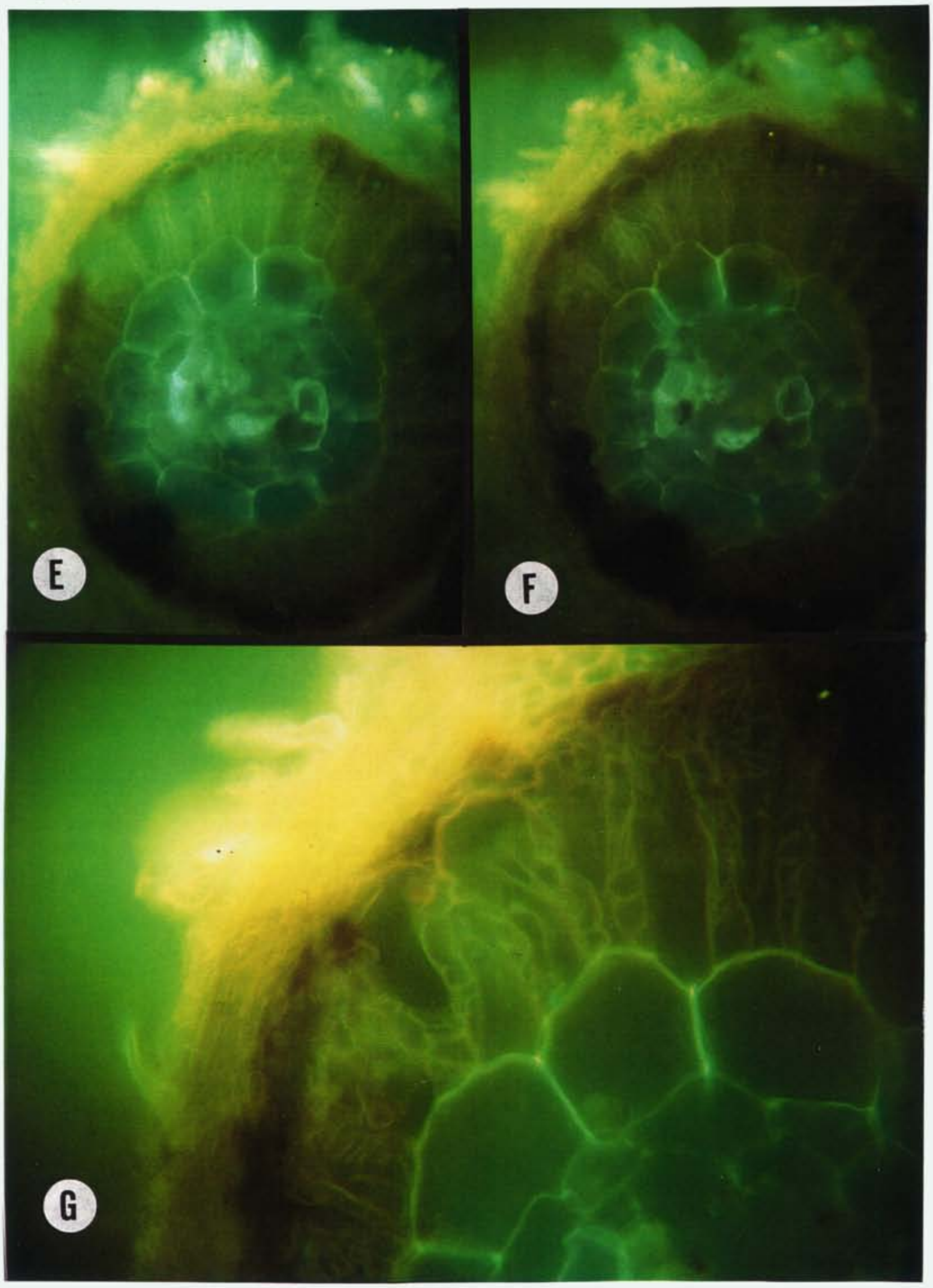
Figure 12-33F: *Piceirhiza nigra* with Morin < 1 mm from tip. There is no evidence of aluminum accumulation. Probe 1K from limed soil at 5-10 cm depth, spring 1999. Cx. 250x. Photo 29-9, clear filter, 15 second exposure, 11 minutes after treatment.

Figure 12-33G: *Piceirhiza nigra* mantle and Hartig net detail. The yellow outer mantle is tightly packed close to the tip in contrast to the worn and damaged structures seen > 5 mm from the tip (Figures 12-33A, 33B), with short emanating hyphal stubs. Detail of the non-fluorescent to dull orange Hartig net is visible up to the distinct bright blue-green cortical cell barrier. Probe 1K from limed soil at 5-10 cm depth, spring 1999. Cx. 1000x. Photo 29-10, clear filter, 60 second exposure, 12 minutes after treatment.

12 - 33



12 - 33



Appendix 12-34: Pseudotomentella tristis - variation?

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare. Abundantly present at 0-10 cm depth in the fall 2000 in unlimed soil and minimally present in limed soil. (Appendices 7-34 and 8A-B3-42).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 84. Growth habit, mycorrhizal systems similar with bluish patches but apices were often white. (Figure 12-34D). Mantle was distinctly gelatinous. (Figures 12-34A, 34B).

Fungal Autofluorescence: In unlimed soil the outer mantle was blue-green and the Hartig net cells were very very faint orange. In limed soil, the outer mantle was blue and the Hartig net cells were non-fluorescent. (Figure 12-34A, 34C)

Root Autofluorescence: Typical. (Xylem, pericycle, endodermis, cortex = blue, phloem = non-fluorescent, hypodermis & epidermis = matched mycorrhizae) (Figure 12-34A, C).

Fungal Aluminum: In unlimed soil, some Al was present in the mantle and Hartig net, while the fungal cells from the limed soil were Al-free. (Figure 12-34B, 34E).

Root Aluminum: In the unlimed soil, Al was evident in the cortex and xylem. In the limed soil, Al was evident in the cortex (but less so) and in the xylem. (Figure 12-34B, E)

Summary: Whether the mantle sequestered aluminum or not did not seem to alter its strong uptake into the unlimed roots. Less Al was present overall within the limed roots and none was present in their mantles.

Figure 12-34A: *Psuedotomentella tristis* autofluorescence < 1 mm, limed. The thick mantle fluoresced bright green while all of the root cells, except the pericycle which was also bright green, fluoresced very faint blue. Probe 900K from limed soil at 0-10 cm depth, fall 2000. Cx. 250x. Photo 31-32, clear filter, 90 second exposure.

Figure 12-34B: *Psuedotomentella tristis* with Morin < 1 mm, limed. There was no aluminum evident in this probe section. Probe 900K from limed soil at 0-10 cm depth, fall 2000. Cx. 250x. Photo 31-33, clear filter, 90 second exposure, 5 minutes after treatment.

Figure 12-34C: *Psuedotomentella tristis* autofluorescence > 5 mm, unlimed. The mantle was green but the cortical cells were dull orange. The endodermis is barely visible as a very faint blue in three patches around the central cylinder and three faint areas of xylem. Probe 900N from unlimed soil at 0-10 cm depth, fall 2000. Cx. 250x. Photo 31-28, clear filter, 15 second exposure.

Figure 12-34D: *Psuedotomentella tristis* gross morphology. The mycorrhizae formed long tortuous tips which tended to have bluish tints often with light reddish apices. The tip shown was a very deep blue-brown in some areas but generally very dark brown and had a whitish instead of a reddish apex. Probe 300N from unlimed soil at 0-10 cm depth in spring 2000. 125x. Photo 5-23.

Figure 12-34E: *Psuedotomentella tristis* with Morin > 5 mm, unlimed. The same section as in Figure 12-34C but aluminum is intensely evident in all cell walls except the non-fluorescent phloem and the three patches of endodermal cells which were bright blue. Probe 900N from unlimed soil at 0-10 cm depth, fall 2000. Cx. 250x. Photo 31-29, clear filter, 15 second exposure, 5 minutes after treatment.

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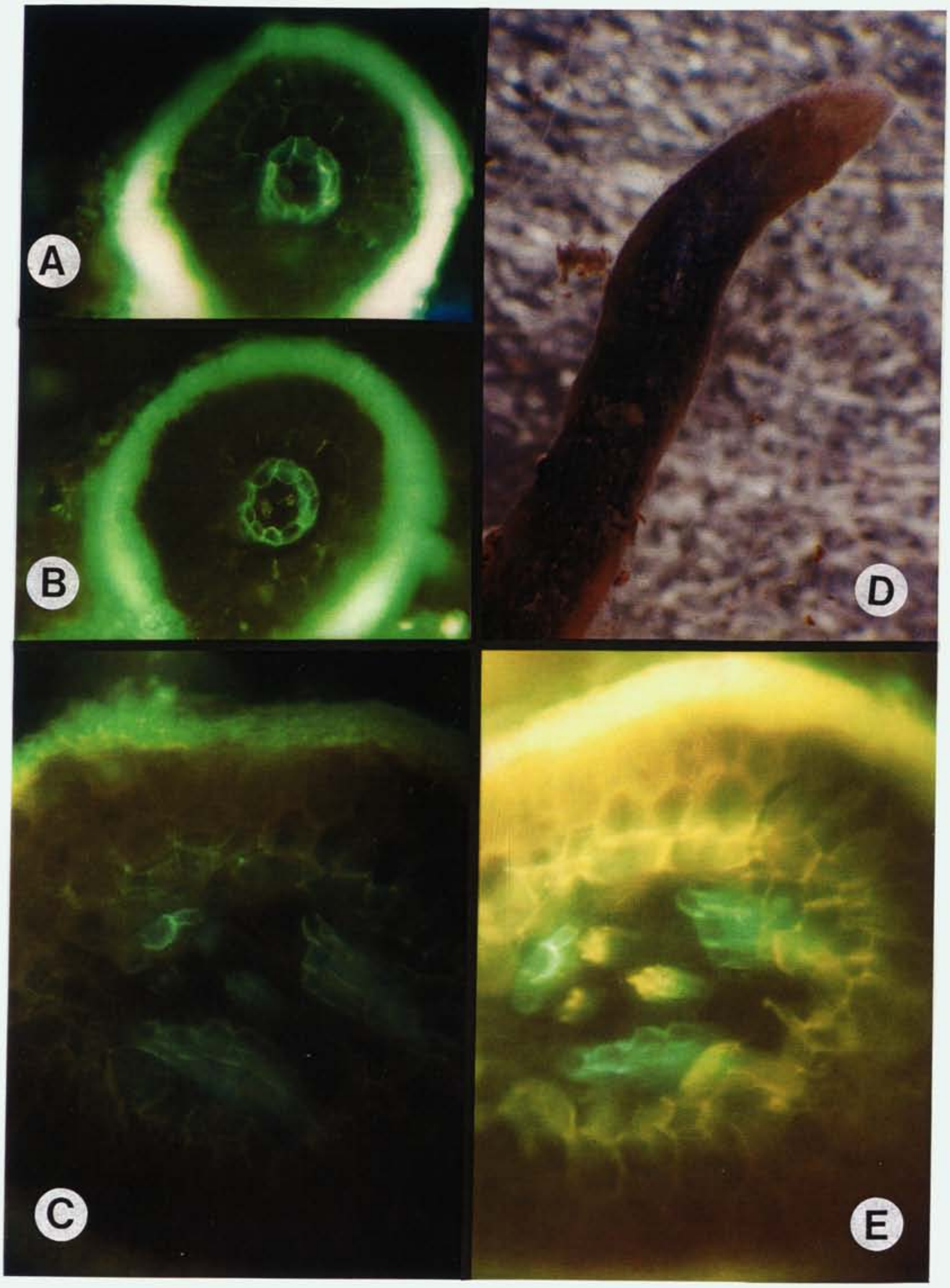

Appendix 12-35: Quercirhiza fibulocystidiata

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Very common. *Quercirhiza fibulocystidiata* was isolated from all depths in both unlimed and limed soils but not consistently from season to season. In limed soil *Quercirhiza fibulocystidiata,* was rarely found in spring and fall 1999, but was more common at 0-10 cm depth in spring 2000, with a strong recovery at 0-10 cm depth in fall 2000. In unlimed soil, it was much less common, with the strongest showings in fall 2000 at 0-10 cm and less so at 30-40 cm depths. Unless adequate moisture is present, the unlimed soil is a less suitable medium for this species (Appendices 7-35 and 8A-B3-43)

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 132. Identifiable by its branched formation, numerous pale cystidia and adhering debris. (Figure 12-35B)

Fungal Autofluorescence: The cystidia, emanating hyphae and outer mantle were identical in fluorescence for any given probe. But the probes varied. In unlimed soil, they varied from faint orange to orange-yellow to yellow-orange to yellow-green to green with the tendency to green increasing with depth and with advancing season. In limed soil, they varied from orange to orange-yellow to yellow-orange to yellow with *No Green* tints and with the tendency to yellow increasing with depth and with advancing season. The invading fungal hyphae in the Hartig net region were generally faint orange in fluorescence but where the Hartig net was poorly formed, the cells were blue to greenish in color. (Figure 12-35a, 35C)

Root Autofluorescence: Typical (xylem, pericycle, endodermis, cortex = blue, phloem = non-fluorescent) except for one probe. At 30-40 cm depth in limed soil, fall 2000, the cells at < 1 mm from tip were: (pericycle = non-fluorescent, cortex, hypodermis & endodermis = yellow) and > 5 mm from the tip were: (phloem = orange, cortex yellow). Extremely heavy deposits of aluminum were also recorded for this aberrant probe. (Figure 12-35C).

Fungal Aluminum: Despite the similarity in natural fluorescence, the cystidia, emanating hyphae and outer mantle cells did not have identical aluminum uptake. In general, the cystidia were often Al-free, while the emanating hyphae usually had an Al content similar to, or slightly less than, that of the mantle. The Hartig net area was more often than not Al-free. In the unlimed probes, the natural green augmentation associated with seasonal aging and depth seemed also to be associated with declining aluminum sequestration. However, the color is problematic since it interferes with interpretation of the Morin-aluminum complex which occasionally produces a green fluorescence. Where the natural greenish fluorescence became "brighter green" a questionable aluminum complex was assumed to be present. Where it became Yellow-green, aluminum was definitely assumed to be present. While less Al seemed to be present with depth and season, more Al seemed to be present with increasing distance from the tips. In limed probes, the natural yellowing associated with seasonal aging and depth was conversely associated with enhanced aluminum uptake. The heaviest aluminum uptake occurred in fall 2000 at 0-10 and 30-40 cm depths. Overall, the least Al was present in the mycorrhiza at 50-60 cm depth. (Figure 12-35D).

Root Aluminum: In the unlimed probes, at 0-10 cm and 30-40 cm depths, Aluminum was absent to variably present in the xylem, and present in the phloem (Spring 2000), pericycle and endodermis (spring & fall 2000) and hypodermics (spring 2000). In the cortex a gradient was often seen where the Aluminum was more concentrated in the outer to central cortical zones and not near the endodermis. At 50-60 cm depth, Al was variable in the xylem and reduced in the cortex but often present in the pericycle and endodermis. The augmentation of Al in the root was often associated with lower concentrations in the mycorrhizal areas.

In limed probes, at all depths, Al was more abundant and consistently evident in the xylem. Occasionally the cortical cells exhibited a banding pattern were Al was equally concentrated in the innermost and outermost regions of the cortex with a band between of greater or lesser concentration. Cortical aluminum concentration increased with probe depth. In fall 2000, Al was found in the hypodermal and epidermal wall in some probes from at 0-10 and 30-40 cm depth and in the pericycle and endodermis at 30-40 cm depth. The augmentation of Al in the root was less frequently associated with lower concentrations in the mycorrhizal areas. (Figure 12-35D)

Summary: Overall, stronger Al accumulation seemed to occur in the limed probes but some unlimed probes had unusual evidence of Al in the phloem, pericycle and endodermis. Unlimed probes also had an usual natural green fluorescence which seemed to be associated with declining Al sequestration.

Figure 12-35A: *Quercirhiza fibulocystidiata* autofluorescence << 1 mm from tip. The mantle is barely developed here but cystidia are clear on the top portion of the cross-section and strongly adhering debris is present over the mantle surface. Fluorescence is strongly green in the mantle but less evident in the Hartig net area. The cortex, incomplete pericycle and xylem are blue-green. Probe is from the only tree in the unlimed plot that died after the test period. Probe 1600N from unlimed soil at 0-10 cm depth in fall 2000. Cx. 250x. Photo 26-16, clear filter, 90 second exposure.

Figure 12-35B: *Quercirhiza fibulocystidiata* gross morphology. The monopodal-pyramidal system with adhering sand crystals. Halo of cystidia visible is visible on the terminal tip. Probe 100K from limed soil at 0-10 cm depth, spring 2000. 125x. Photo 3-7.

Figure 12-35C: *Quercirhiza fibulocystidiata* autofluorescence < 1 mm from tip. The cystidia and mantle fluoresced green to bright yellow and the Hartig net was mostly dull orange while the root cells were blue. Probe 1000K from limed soil at 0-10 cm depth in fall 2000. Cx. 250x. Photo 17-8, clear filter, 90 second exposure.

Figure 12-35D: *Quercirhiza fibulocystidiata* with Morin < 1 mm from tip. Where the cystidia were evident on the mantle heavy aluminum uptake occurred in the mantle, Hartig net and cortical cells, while where the mantle was tightly covered with adhesive sandy debris, less aluminum was evident. Probe 1000K from limed soil at 0-10 cm depth in fall 2000. Cx. 250x. Photo 17-10, clear filter, 45 second exposure, 5 minutes after treatment.

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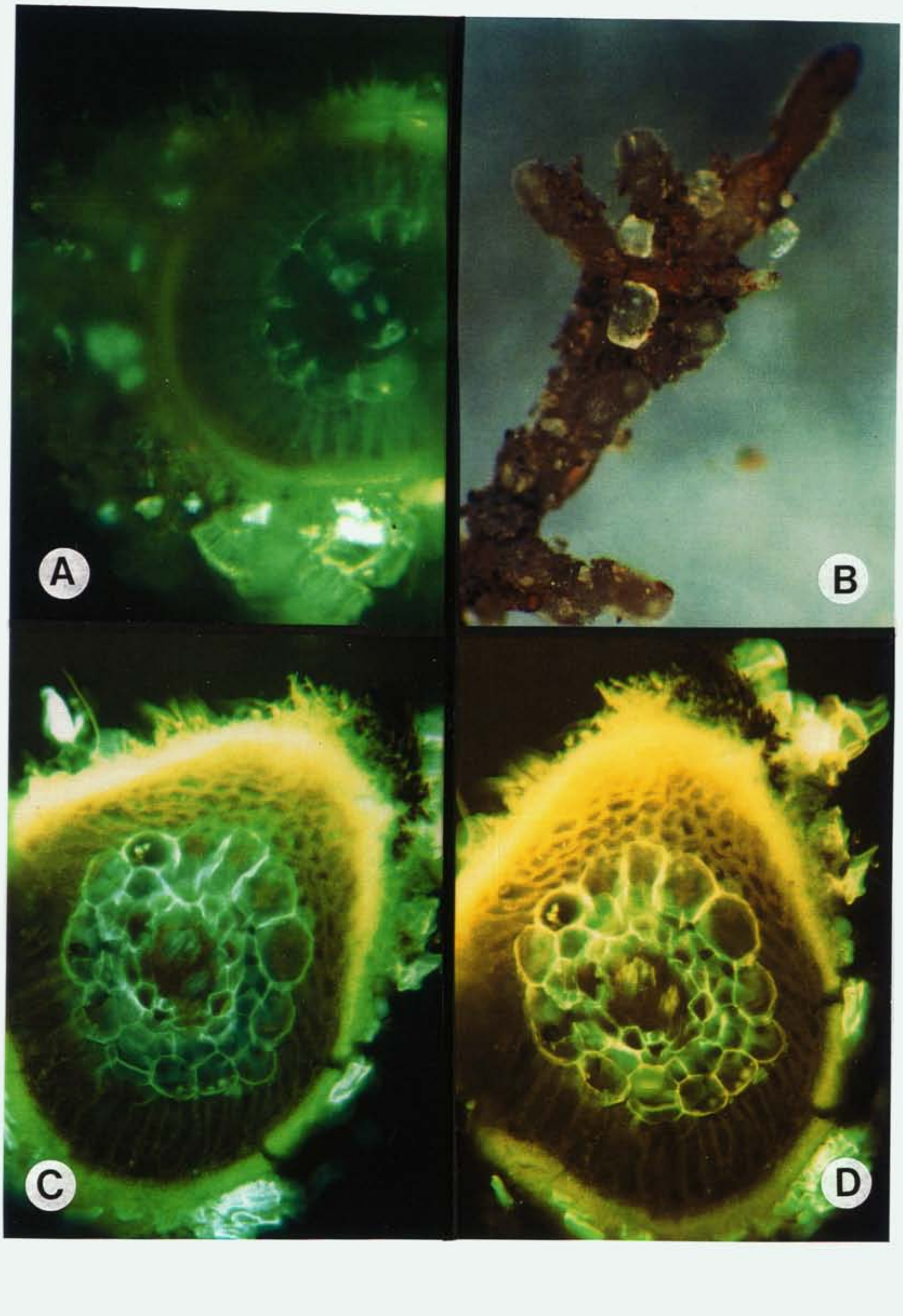

Appendix 12-36: Quercirhiza squamosa

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Quercirhiza squamosa* was found at all soil depths in both forest zones, but was most common in unlimed soils, especially in spring 2000. In limed soils the mycorrhiza was somewhat less common in spring 1999, but never fully recovered from the subsequent drought. (Appendices 7-36 and 8A-B3-44).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 86. (Figure 12-36A)

Fungal Autofluorescence: The mantle and emanating hyphae were non-fluorescence < 1 mm, but tended to become fluorescent > 5 mm from the tip. The Hartig net area, at 0-10 cm depth, was very faint blue-green (1999) to non-fluorescent (2000) in limed soil or consistently faint orange in unlimed soil. At 30-40 cm depth, the Hartig net was faint orange in both cases while at 50-60 cm depth it was faint orange (spring) to blue (fall). (Figure 12-36B, 36E)

Root Autofluorescence: Typical except for two rare where the immature phloem was blue. (Figure 12-36B, 36E).

Fungal Aluminum: Normally the mantle and hyphae were Al-free except for occasional specks. In unlimed soil, the Hartig net was mostly Al-free at 0-10 cm but contained more Al with depth of samples. In limed soil, the reverse was true, the Hartig net contained more Al at 0-10 cm but contained less Al with increased depth. (Figure 12-36C,D,F).

Root Aluminum: The amount of Al in the Hartig net was occasionally inversely proportional to the amount in the xylem. In unlimed soil, at 0-10 cm depth, Al was variably absent to present in the xylem and weakly to moderately present in the cortex At 30-40 cm depth, Al was strongly and consistently present in the xylem and cortex, but less evident at 50-60 depth. Some Al was present in the phloem especially in the spring of

1999. In limed soil, at 0-10 cm depth, Al was variably absent to present in the xylem and weakly to strongly present in the cortex. At 30-40 cm depth, Al was more strongly and consistently present in the xylem and cortex in comparison to the 50-60 cm depth probes where it was consistent but not as strongly present. Some Al was present in the phloem especially in the spring of 1999 and fall 2000. (Figure 12-36C,D,F).

Summary: Somewhat more Al was evident in the limed probes but overall both were very similar in Al content relative to soil depth. There were weak tendencies where an increase in Al in the Hartig net was associated with a decline in Al in the cortex and vica versa.

Figure 12-36A: *Quercirhiza squamosa* gross morphology. The black ectomycorrhiza is characterized by a ramified, monopodal -pinnate to -pyramidal system with densely arranged emanating brown, irregularly bent, hyphae. The single tip of a "tree" is shown with its hyphae and some adhering debris. Probe 400N from unlimed soil at 0-10 cm depth, spring 2000. 320x. Photo 6-33.

Figure 12-36B: *Quercirhiza squamosa* autofluorescence < 1 mm from tip. The mantle, minimal Hartig net and emanating hyphae are non-fluorescent. Cortical cells and endodermis are faint blue-green and the xylem is bright blue. Fluorescent debris is visible near the outer mantle regions. NOTE: Autofluorescence changes with distance from the ectomycorrhizal tip (Fig. 12-36D, 36E). Probe 10K from limed soil at 0-10 cm depth, fall 1999. Cx. 400x. Photo 25-10, clear filter, 10 second exposure.

Figure 12-36C: *Quercirhiza squamosa* with Morin < 1 mm from tip. The fungal mantle has a few specks of aluminum randomly associated with the mantle. Some of the quenched debris was Al-free while other pieces of debris contained Al. The Cortical and xylem cell walls show strong aluminum content while the endodermal and pericycle cells remained blue-green but appear brighter most likely due to strong adjacent luminescence. Probe 10K from limed soil at 0-10 cm depth, fall 1999. Cx. 400x. Photo 25-13, clear filter, 15 second exposure, 15 minutes after treatment.

Figure 12-36D: *Quercirhiza squamosa* Hartig net 1 mm from tip, with Morin. The well defined Hartig net which fluoresces dull green while the outer mantle is still non-fluorescent to very faint green using a green filter. (The Hartig net region was slightly brighter after Morin treatment implying minimal Al content). The cortical regions and two xylem areas in the central zone show strong Aluminum content. Probe 1KA, from limed soil 30-40 cm depth in spring 1999. Cx. 400x. Photo 9-15, green filter, 8 second exposure, 5 minutes after treatment.

Figure 12-36E: *Quercirhiza squamosa* autofluorescence > 5 mm from tip. The mantle autofluorescence changes from non-fluorescent (<< 1 mm) (Fig. 12-36A) to very faint green (Fig. 12-36D) to yellow - green in areas > 5 mm from the tip. The Hartig net which was poorly formed and non-fluorescent (<< 1 mm) (Fig. 12-36A) becomes dull yellow-green when well formed (Fig. 12-36D) and dull green in older collapsed regions. The cortical cells, which are damaged here, tend to fluoresce bright blue-green. The pericycle ring which is 3 layers thick is very bright blue-green, while the phloem is non-fluorescent and the mature xylem region (bottom) is green-blue in autofluorescence. *Quercirhiza squamosa* consistently exhibited this developmental autofluorescent pattern. Probe 1K, from limed soil at 0-5 cm depth, spring 1999. Cx. 400x. Photo 6-20, clear filter, 8 second exposure.

Figure 12-36F: *Quercirhiza squamosa* with Morin > 5 mm from tip. The strongest Aluminum accumulations occurred in the cortex and xylem. Probe 1K, from limed soil at 0-5 cm depth, spring 1999. Cx. 400x. Photo 6-21, clear filter, 8 second exposure, 5 minutes after treatment.

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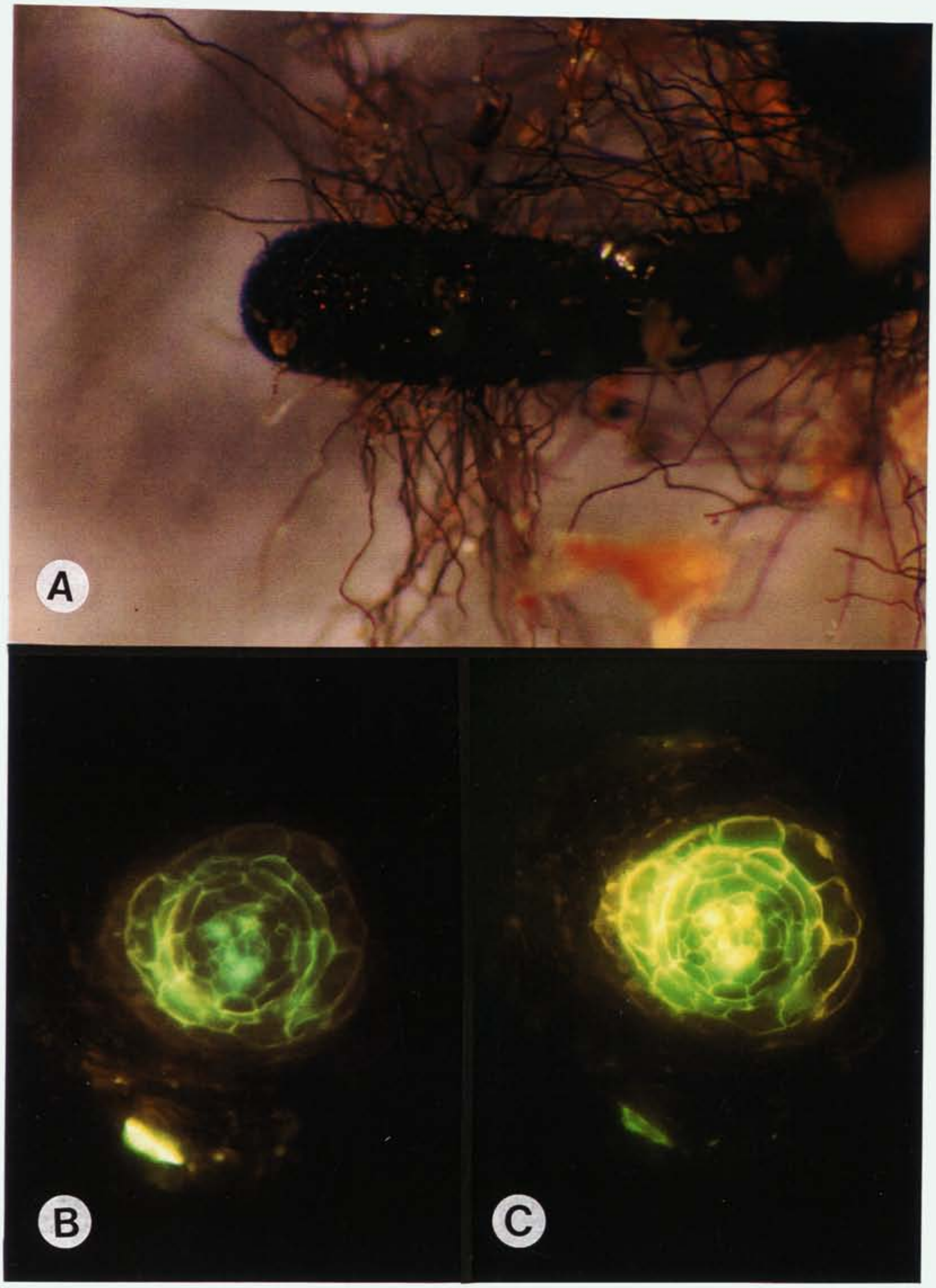
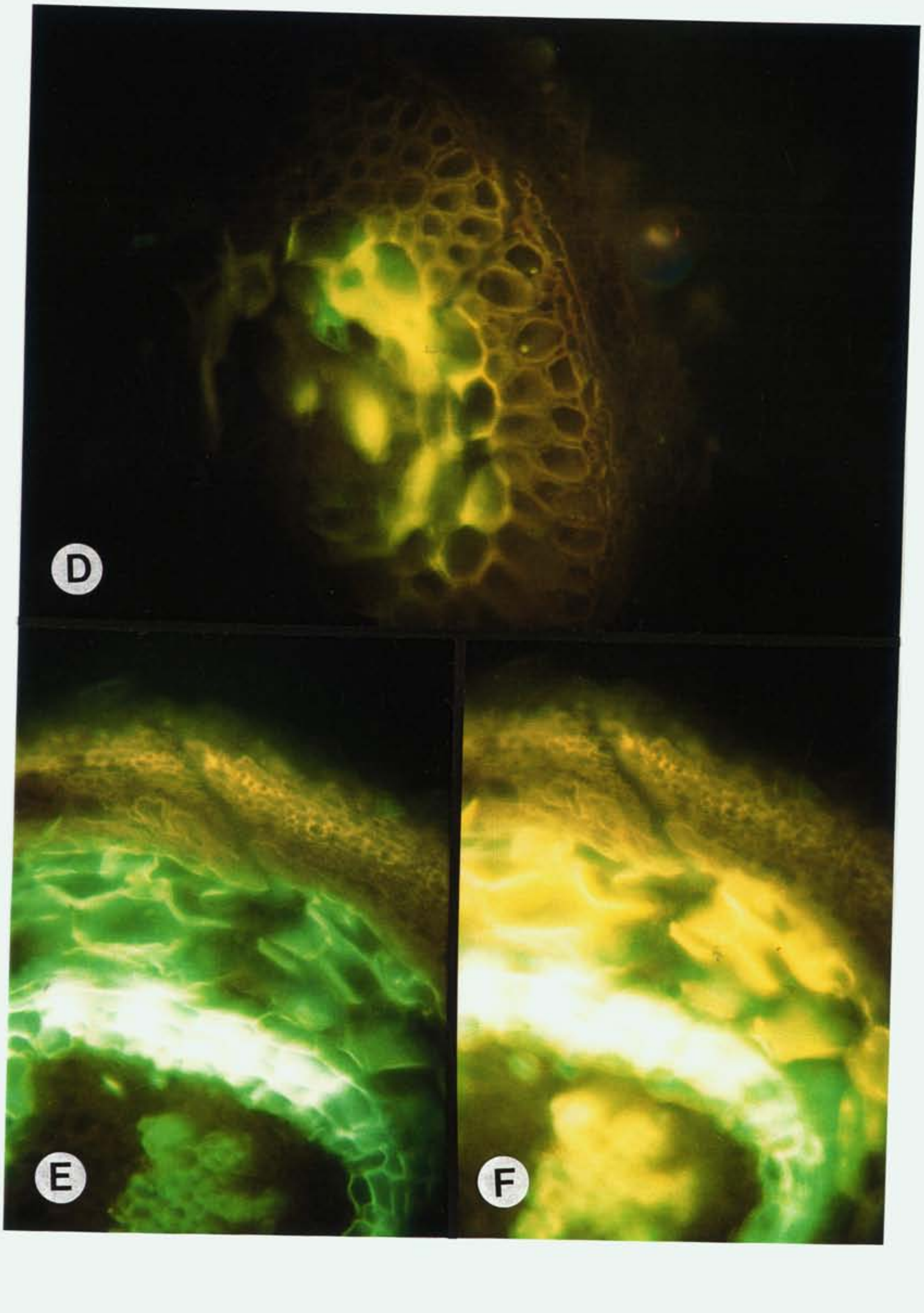


12- 36



Appendix 12-37: Quercirhiza sublutea

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare, found only in 0-10 cm depth in the spring (strong presence in unlimed and weak in limed) and fall of 2000 (approximately equal in abundance in both forest zones) (Appendices 7-37 and 8A-B3-45).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 133. (Figure 12-37A).

Fungal Autofluorescence: In unlimed soil, the mantle was orange-yellow to faint orange with a faint green outer portion. In limed soil, the mantle was yellow-green to faint yellow-orange. The Hartig net cells were faint orange with immature portions being faint blue. (Appendix 7-37).

Root Autofluorescence: Typical.

Fungal Aluminum: All the mantle cells contained some Al, but in the spring samples, the color change to brighter yellow- green was extremely slow (20 minutes) implying a very low Al content. The fall changes were slightly faster. In the unlimed soil, the Hartig net cells contained slightly more Al than those from the limed soil. (Figure 12-37B, 37C).

Root Aluminum: In both cases, the xylem strongly contained aluminum. In the unlimed probes, the cortex was Al-free to variable in the spring samples but contained strong aluminum content in the fall. In the limed probes, the cortex strongly contained Al in the spring and less evidently so in the fall. (Figure 12-37B, 37C).

Summary: In the unlimed samples, more Al seems to be present in the fall in both the root an mycorrhizae, while the limed samples contained more aluminum in the spring in the spring but less in the mycorrhizae. More samples are needed to be certain of the physiology.

Figure 12-37A: ***Quercirhiza sublutea*** **gross morphology.** The mycorrhizal system was irregularly monopodal pinnate to pyramidal with long laterals that were either straight or bent as depicted with tapering tips. The outer mantle surface was smooth and occasionally silvery with an underlying rosy brown cast in the longer tips. No rhizomorphs are visible in this photo. Probe 400N from unlimed soil at 0-10 cm depth in spring 2000. 160x. Photo 7-16.

Figure 12-37B: ***Quercirhiza sublutea*** **with Morin < 1 mm from tip.** The normal autofluorescence of the mantle was faint orange-green but with Morin it became intense yellow. The only cells here that did not show strong aluminum content were the phloem and the 2 pairs of incomplete pericycle cells. This sample was extracted from the only tree in the unlimed plot that died immediately after the 1999-2000 test period. Probe 1600N from the unlimed soil at 0-10 cm depth in fall 2000. Cx. 250x. Photo 26-3, clear filter, 60 second exposure, 25 minutes after treatment.

Figure 12-37C: ***Quercirhiza sublutea*** **with Morin, Hartig net detail.** The mantle varied in its aluminum content with the brightest yellow areas in the outer mantle while the middle mantle had less Al (bright green) and the innermost mantle was orange. The fungal cells of the Hartig net had less Al (green) than the extremely bright yellow cortical cells. Probe 1600N from the unlimed soil at 0-10 cm depth in fall 2000. Cx. 1000x. Photo 26-6, clear filter, 60 second exposure, 40 minutes after treatment.

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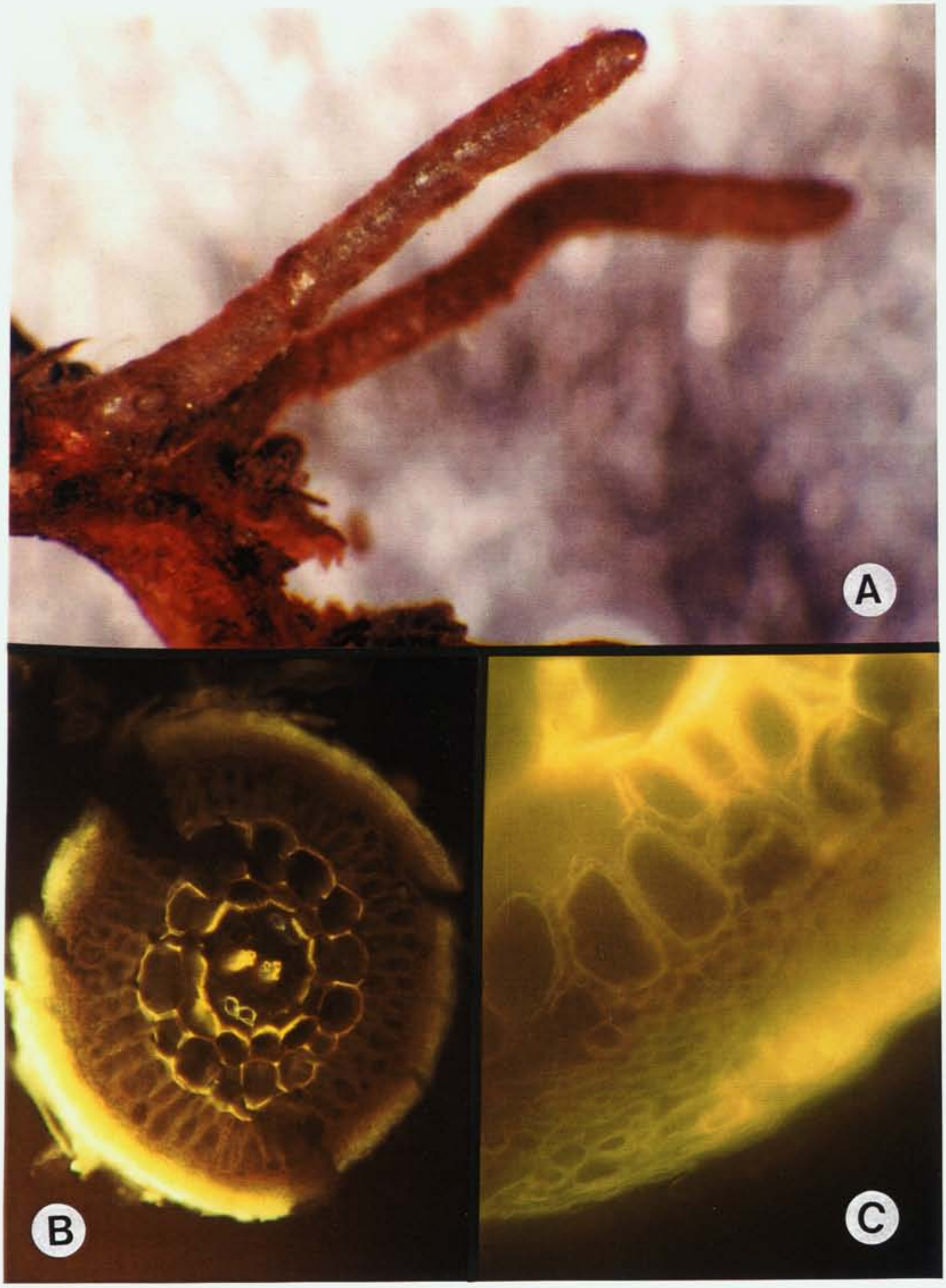


Appendix 12-38: Russula acrifolia

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Not common in dry soil. *Russula acrifolia* was isolated from 0-10 cm depth in the wet spring and fall 2000 from both plots. It was most common on limed moist soils, especially in the spring (Appendices 7-38 and 8A-B3-46).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 105. (Figure 12-38A).

Fungal Autofluorescence: In the unlimed soil the mantle and cystidia fluoresced yellow-green in the spring and faint green in the fall while the Hartig net cells were faint orange. In the limed soil the mantle and cystidia were faint yellow-green in the spring and faint green the fall but the Hartig net cells were non-fluorescent. (Figure 12-38B).

Root Autofluorescence: Typical. (Figure 12-38B).

Fungal Aluminum: In the unlimed soil, the mantle and cystidia cells contained some aluminum in the fall but not the spring. In the limed soil, the mantle and cystidia cells in contrast contained some aluminum in the spring but not the fall. (Figure 12-38C).

Root Aluminum: In the unlimed soil aluminum was variably present in the spring but more strongly present in the xylem and cortex in the fall. In limed soil, conversely, aluminum was more strongly present in the spring but absent in the fall. In both cases, the presence of aluminum in the mantle was correlated with the presence of aluminum in the cortex and xylem. (Figure 12-38C).

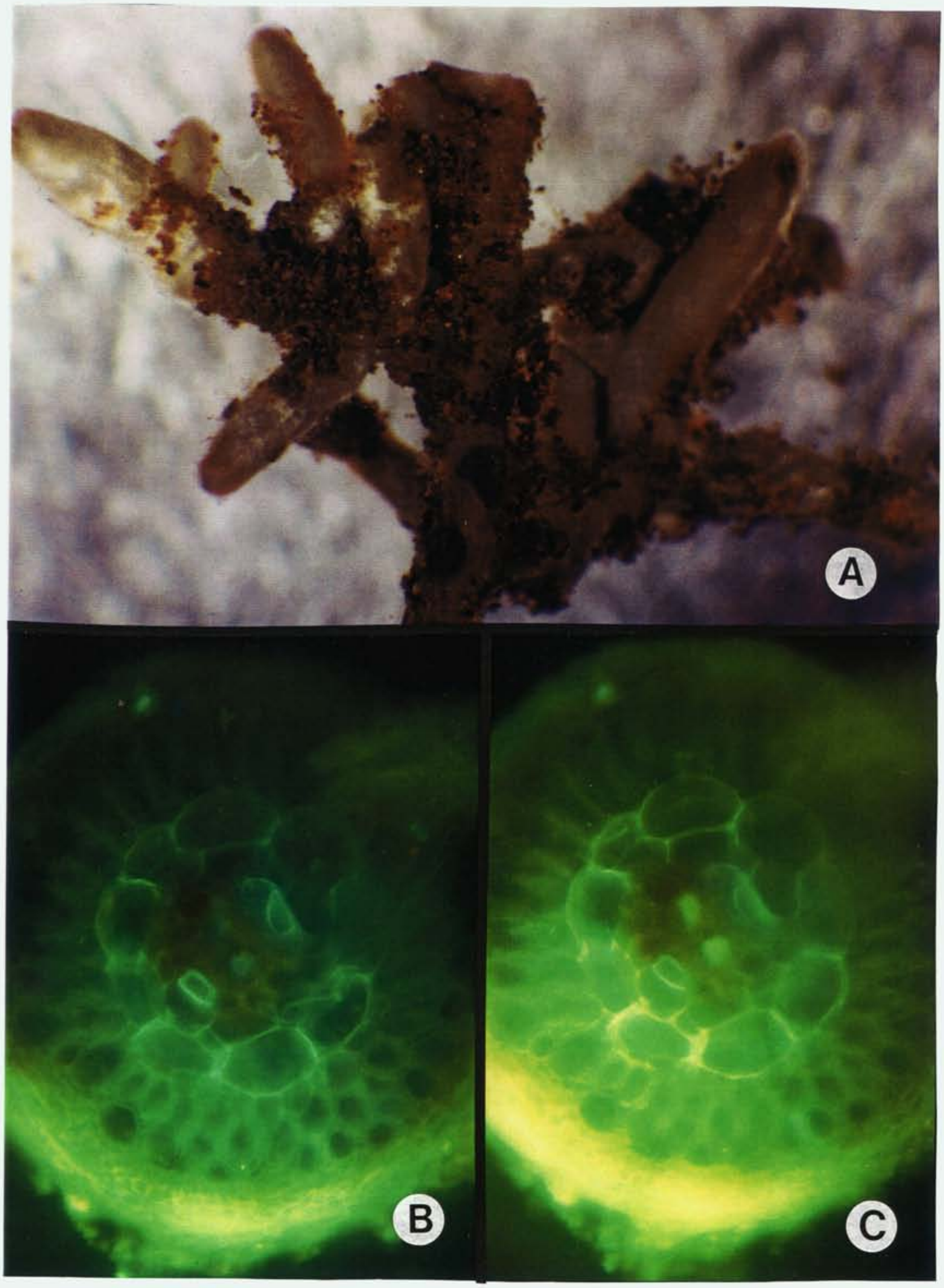
Summary: The presence of aluminum in the mycorrhizal sheath was directly correlated to its augmented presence in the xylem and cortex in the unlimed (fall only) and limed (spring only) probes. Although liming did not apparently affect the mycorrhizal wall depositions it may have altered the time during which aluminum was available to the roots.

Figure 12-38A: *Russula acrifolia* gross morphology. The mycorrhizae forms a monopodal-pyramidal system with some silvery patches and a great deal of adhering debris. Cystidia are faintly evident in lower left branch and a thin clear rhizomorph is barely visible in the upper left between the two tips. Probe 400N from unlimed soil at 0-10 cm depth, spring 2000. 125x. Photo 7-2.

Figure 12-38B: *Russula acrifolia* autofluorescence < 1 mm from tip. The mantle is primarily very weakly green in fluorescence with some yellow-green regions while the Hartig net is green to orange-green (lower area) to non-fluorescent (upper area). This area is very close to the tip and so there is only one layer of large cortical cells which are blue-green and an incomplete endodermis with two cells in apposition to the two central xylem tubes, both blue-green. The phloem in the central cylinder is very faint orange. Probe 900N from unlimed soil at 0-10 cm depth, fall 2000. Cx. 400x. Photo 39-21, clear filter, 30 seconds exposure.

Figure 12-38C: *Russula acrifolia* with Morin < 1 mm from tip. The root shows aluminum present only in the lower left quadrant, within the mantle, Hartig net and cortical cells. Despite the incomplete endodermal barrier, there is no aluminum in the xylem. Probe 900N from unlimed soil at 0-10 cm depth, fall 2000. Cx. 400x. Photo 39-22, clear filter, 30 seconds exposure, 5 minutes after treatment.

12 - 38



Appendix 12-39: Russula fuegiana

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare. *Russula fuegiana* was isolated only at 0-10 cm depth in spring of 2000 in both zones. It was most common in unlimed soil however in fall 2000 (Appendices 7-39 and 8A-B3-48).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 106.

Fungal Autofluorescence: In both the unlimed and limed probes, the emanating hyphae and mantle fluoresced intense green, especially near the tips with the outer mantle being the most intense. The inner mantle and Hartig net area hyphae were faint orange-green. (Figure 12-39A, 39B)

Root Autofluorescence: Typical blue to green blue. (Figure 12-39A, 39B)

Fungal Aluminum: No aluminum was present in the mycorrhizae from either the unlimed or limed plots. (Figure 12-39C). It is quite possible that the natural fluorescence of the mantle masked any aluminum that may have been present in small amounts since the fluorescence was often a little brighter after Morin treatment. (Figure 12-39C).

Root Aluminum: Aluminum was variably present in the cortex only, especially near the endodermal barrier close to the tip, in both the unlimed and limed samples. (Figure 12-39C shows that the unlimed probe from spring 2000 was Al-free).

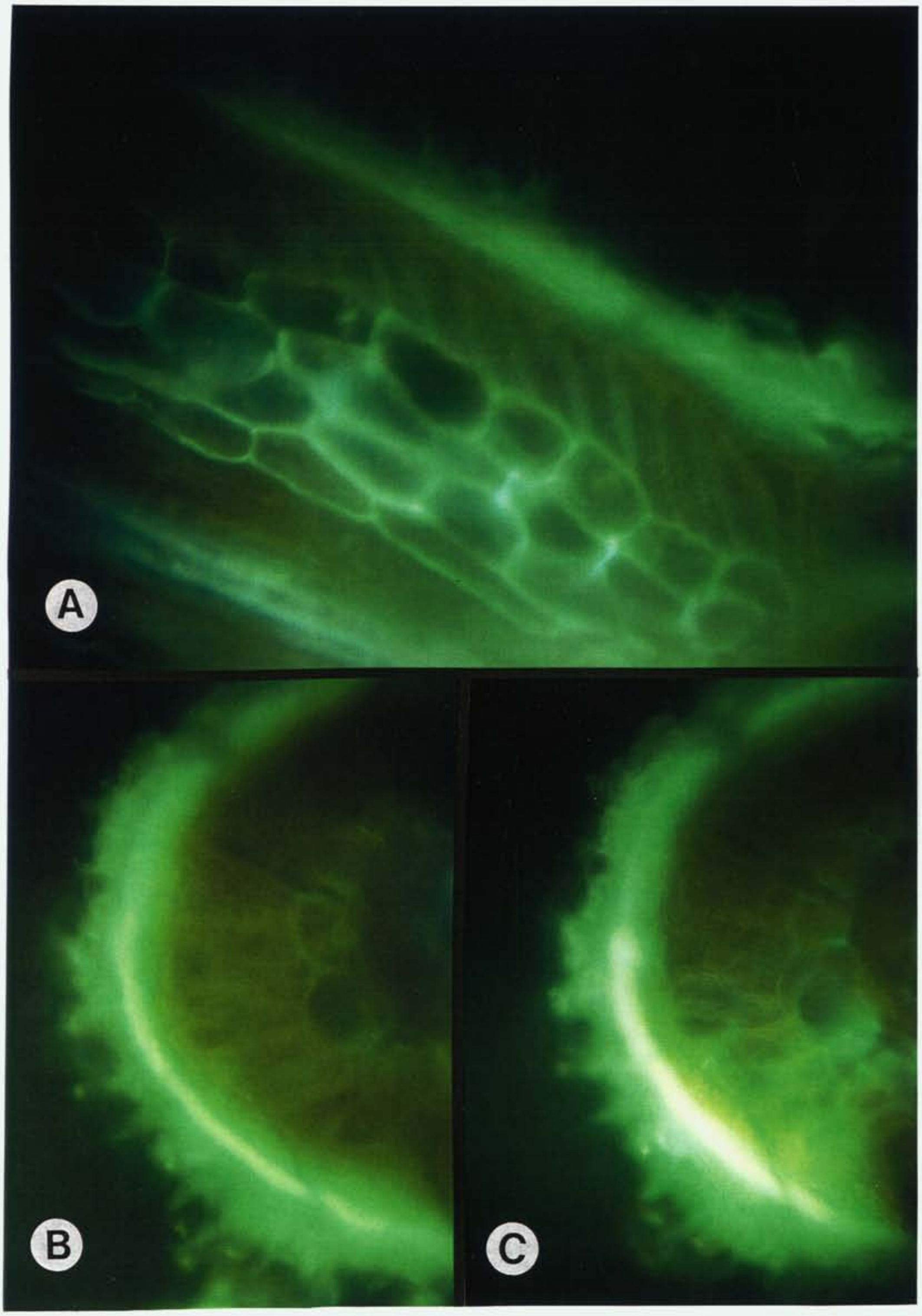
Summary: These mycorrhizae were very small and young, seeming to appear only for a short time and may not have had time to accumulate aluminum as would some other species which can live for several years continuously in the soil.

Figure 12-39A: *Russula feugiana* autofluorescence > 5 mm from tip. The outer mantle and emanating cystidia fluoresce bright green while the inner mantle and Hartig net between the radially elongated root cells are dull orange-green. The large cortical cells are blue to blue green as are the laterally elongated endodermal and xylem cells. The non-fluorescent phloem appears in the diffused light from the endodermal and xylem cells at the bottom left. Probe 100N from unlimed soil at 0-10 cm depth, spring 2000. Lx. 400x. Photo 34-27, clear filter, 30 second exposure.

Figure 12-39B: *Russula feugiana* autofluorescence < 1 mm from tip. The fluorescence is similar to Figure 12-39A except that the outer mantle cells are brighter than the cystidia or inner mantle cells. Probe 100 N 0-10 cm. Cx. 400x. Photo 34-30, clear filter, 30 second exposure.

Figure 12-39C: *Russula feugiana* with Morin < 1 mm from tip. The fluorescence is much the same as in Figure 12-39B indicating little, if any, aluminum is present except perhaps in the outer mantle region which is bright yellow. Probe 100 N 0-10 cm. Cx. 400x. Photo 34-31, clear filter, 30 second exposure, 5 minutes after treatment.

12 - 39



Appendix 12-40: Russula mairei

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare. *Russula mairei* was isolated from 0-10 cm depth in spring and fall 2000 from both zones. It was most common in unlimed soil in spring 2000 but more prevalent in fall 2000 in the limed probes. In limed soil it was found only in the upper horizon but in unlimed soil it was found at 30-40 (spring 2000) and 50-60 (spring 1999) cm depths (Appendices 7-40 and 8A-B3-50).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 65. (Figure 12-40A).

Fungal Autofluorescence: In the unlimed soil the outer mantle was two-toned: orange in the proximal areas and pale green in the distal areas, while the Hartig net cells were faint orange-blue. In the limed soil, the mantle was non-fluorescent to faint yellow-green in the external areas while the Hartig net cells were very faint orange.

Root Autofluorescence: Typical.

Fungal Aluminum: In the unlimed soil, the mantle became faint green throughout implying very small amounts of aluminum and in the limed soil the mantle became intensely yellow-green but only in the external areas. The Hartig net cells were Al-free in both cases

Root Aluminum: In the unlimed soil, the xylem were variable in their aluminum content while the cortical cells had intense deposits near the endodermal barrier and were Al-free near the hypodermis. In limed soil, the xylem strongly contained aluminum as did the entire cortex.

Summary: More aluminum was evident in the limed samples than in the unlimed samples which were often Al-free. Liming seemed to alter the chemical structure of the outer mantle as evidenced by the differential fluorescence.

Figure 12-40A: *Russula mairei* gross morphology. Typified by pale coloration, warty surface and extremely fine emanating hyphae. Probe 100N from unlimed soil at 0-10 cm depth, spring 2000. 200x. Photo 3-28.

Figure 12-40B: *Russula ochroleuca* gross morphology. Typified by ochre mounds on surface of mantle. Collected October 17, 2001 from unlimed zone. 320x. Photo 18-23.

12-40

Appendix 12-41: Russula ochroleuca

Fruiting body Occurrence: Very common in both unlimed and limed zones.

Mycorrhizal Occurrence: Common. *Russula ochroleuca* was present only at 0-10 cm depth. It was most common in fall 2000, especially in the limed plot. In the limed zone it was also prevalent during the drought (fall 1999) (Appendices 7-41 and 8A-B3-51).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 1. Most easily identified by large ochre yellow spots on mantle surface. (Figure 12-40B)

Fungal Autofluorescence: In unlimed soil, the outer mantle was two-toned with the outer cells fluorescing orange and the inner cells fluorescing yellow. In limed soil, the outer mantle was two-toned with the outer cells fluorescing yellow while the inner cells fluoresced blue. In both cases, Hartig net cells were faint orange. The mounds of ochre-yellow on the mantle surface appeared pale green to intensely yellow. (Figure 12-41B).

Root Autofluorescence: Typical. (Figure 12-41B)

Fungal Aluminum: In the unlimed probes, Al was present throughout the mycorrhizal area, including the Hartig net, but was most intense in the *inner mantle* (near the root epidermal cells). In the limed probes, Al was also present throughout the mycorrhizal area but was most intense in the *outer mantle*. (Figure 12-41A, 41C).

Root Aluminum: In unlimed probes, Al was weakly present in the xylem and variable in the cortex with the most aluminum in the distal cells. In the limed probes, Al was variable in the xylem and strongly present in the cortex in most cases (Figure 12-41A, 41C).

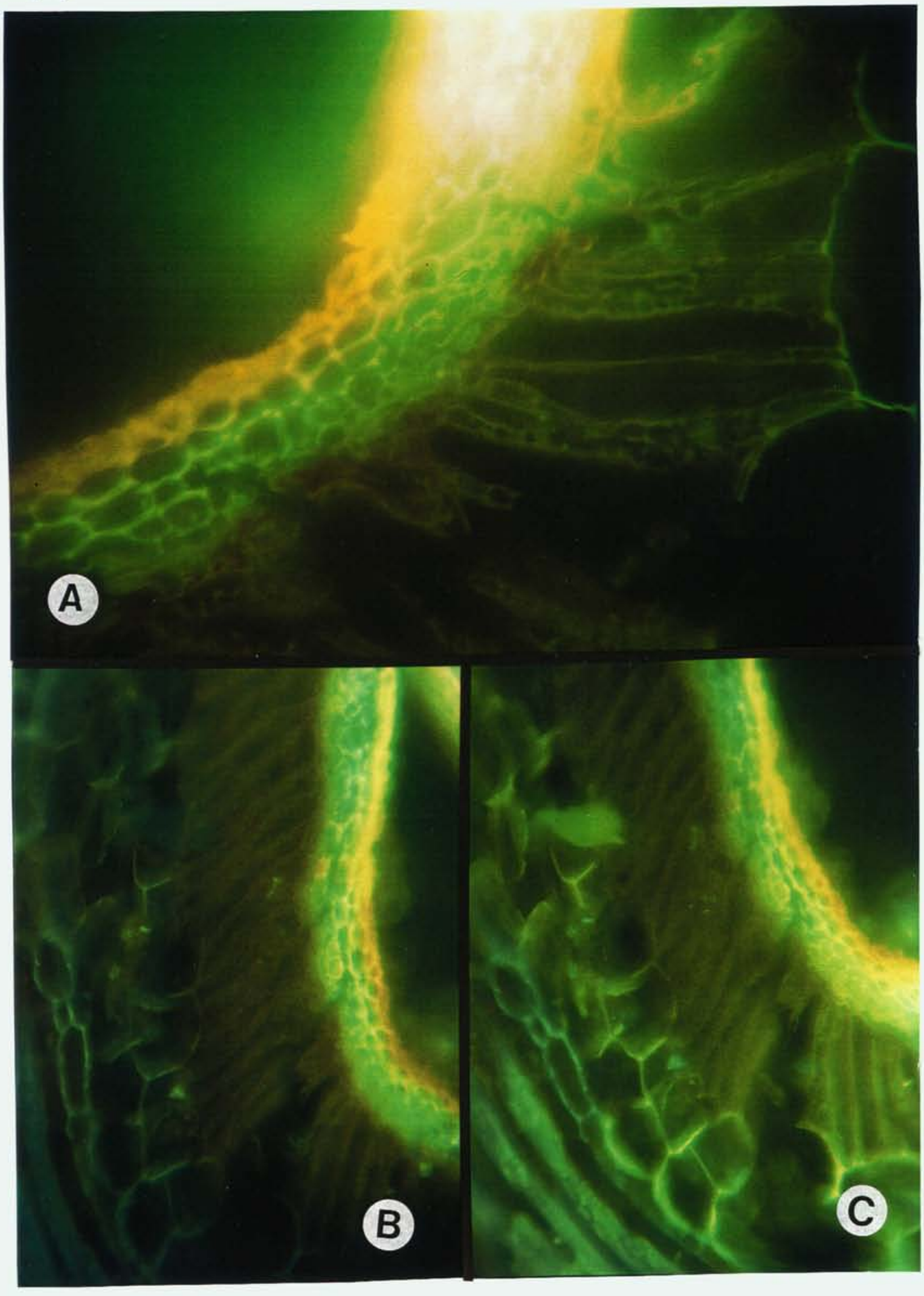
Summary: Liming seemed to alter aluminum uptake resulting in more deposition in the cortical regions and less translocation to the xylem. In the unlimed probes, less aluminum was present in the cortex but more reached the xylem.

Figure 12-41A: ***Russula ochroleuca* showing detail of Hartig net.** The region shown is > 5 mm from the tip. The outer mantle is deep yellow with an intense region of aluminum accumulation (bright yellow) while the inner mantle is low in aluminum (bright green). The Hartig net is visible between the elongated outer root cells with some green Aluminum specks. The large round cortical cells are visible to the right and appear to be aluminum free. Probe 800K from limed soil at 0-10 cm depth. Lx. 1000x. Photo 35-13, clear filter, 90 second exposure, 12 minutes after treatment with Morin.

Figure 12-41B: ***Russula ochroleuca* autofluorescence > 5 mm from tip.** The outer mantle is bright orange-yellow and the inner mantle is blue, typical of limed probes. The Hartig net, around elongated root cells, is dull orange. The large cortical cells are faint blue while the xylem is brighter blue (bottom right of image). Probe 800K from limed soil at 0-10 cm depth. Lx. 400x. Photo 35-9, clear filter, 15 second exposure.

Figure 12-41C: ***Russula ochroleuca* with Morin > 5 mm from tip.** The outer mantle and Hartig net have not changed but there is evidence of faint aluminum presence in the cortex and xylem (brighter green). Probe 800K from limed soil at 0-10 cm depth. Lx. 400x. Photo 35-10, clear filter, 15 second exposure, 5 minutes after treatment.

12-41



Appendix 12-42: Tuber melanosporum

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Tuber melanosporum* was most common in spring 1999 in the unlimed soil where it was most prevalent at 0-10 cm and frequent at 50-60 cm depths. In limed soil it was somewhat frequent in spring 1999 at 30-40 cm depth and in fall 2000 at 0-10 cm depth, otherwise it was rarely seen. (Appendices 7-42 and 8A-B3-54).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 87. Identified by the plectenchymatous net with blunt ended, long, warty cystidia branching perpendicularly from the net which loosely covers the epidermoid mantle cells at the mycorrhizal tips. (Figure 12-42D).

Fungal Autofluorescence: In both unlimed and limed probes the outer mantle and emanating hyphae were pale yellow in fluorescence while the Hartig net cells were faint orange. In the unlimed soil in fall 1999, some of the outer mantle and emanating hyphae had orange tendencies and were blue > 5 mm from the tips. (Figure 12-42A, 42B)

Root Autofluorescence: Typical. (Figure 12-42A, 42B)

Fungal Aluminum: In unlimed soil, the outer mantle, emanating hyphae and Hartig net cells all contained aluminum in spring 1999 but were mostly Al-free in fall 1999 with some Al reappearing in the spring 2000. In limed soil, only the outer mantle and emanating hyphae contained aluminum in spring 1999 but in the fall 1999, aluminum was heavily present in Hartig net and mantle cells > 5 mm from the tip. (Figure 12-42C)

Root Aluminum: In unlimed soil, aluminum was variably absent to present in the xylem and the cortex but with some increase in intensity over time. In the cortex, Al seemed to accumulate in the cortex near the endodermis while the distal cortical cells were usually Al-free. Where Al was more strongly present in the mantle, it was variable and less intense elsewhere. In the spring of 2000, when Al was weakest in the mantle, some Al was evident in the phloem. In limed soil, aluminum was more consistently present in the xylem and cortex in the spring but in the fall, when it was more strongly present in the mantle, it was variable and reduced elsewhere. (Figure 12-42C).

Summary: Liming seemed to reduce aluminum deposition in the Hartig net area in spring but improve deposition in the outer mantle in fall. Where Al was more strongly present in the mantle, it was more variable (reduced) elsewhere in the root in both unlimed and limed probes and conversely where it was weak in the mantle, Al was more evident in the root cells. It could not be determined which probes contained more aluminum overall.

Figure 12-42D : *Tuber melanosporum* A: Surface mantle epidermoid cells; B: Plectenchymatous net over epidermoid cells, with blunt ended, long, warty cystidia branching perpendicularly. Surface attachment site (AS) with emanating hyphae shown.

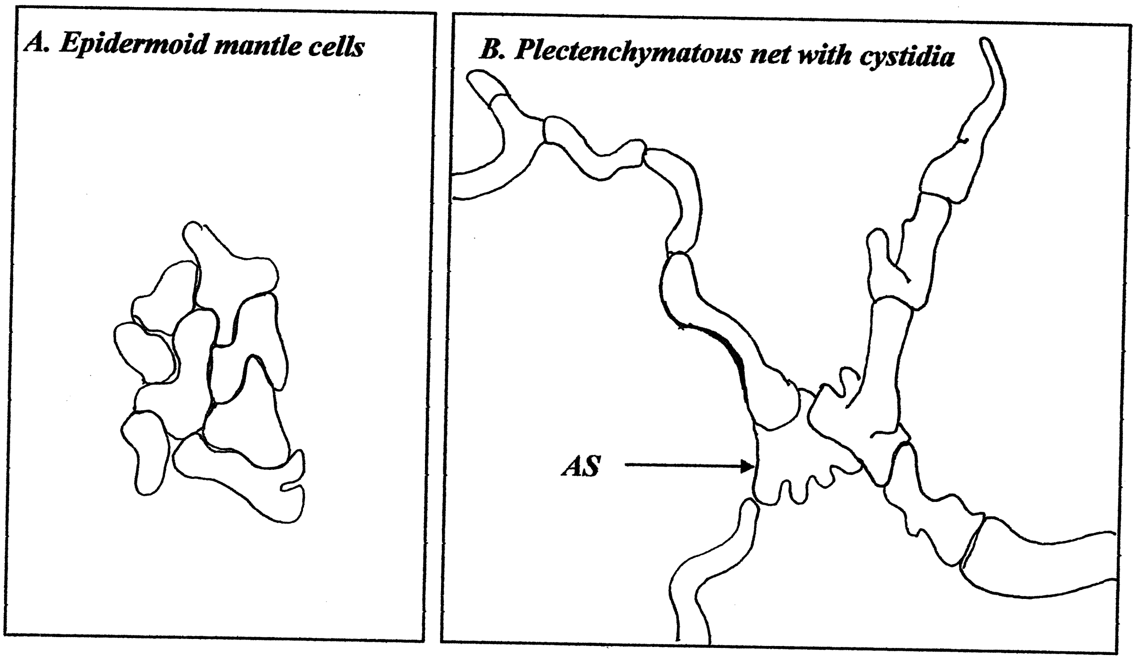
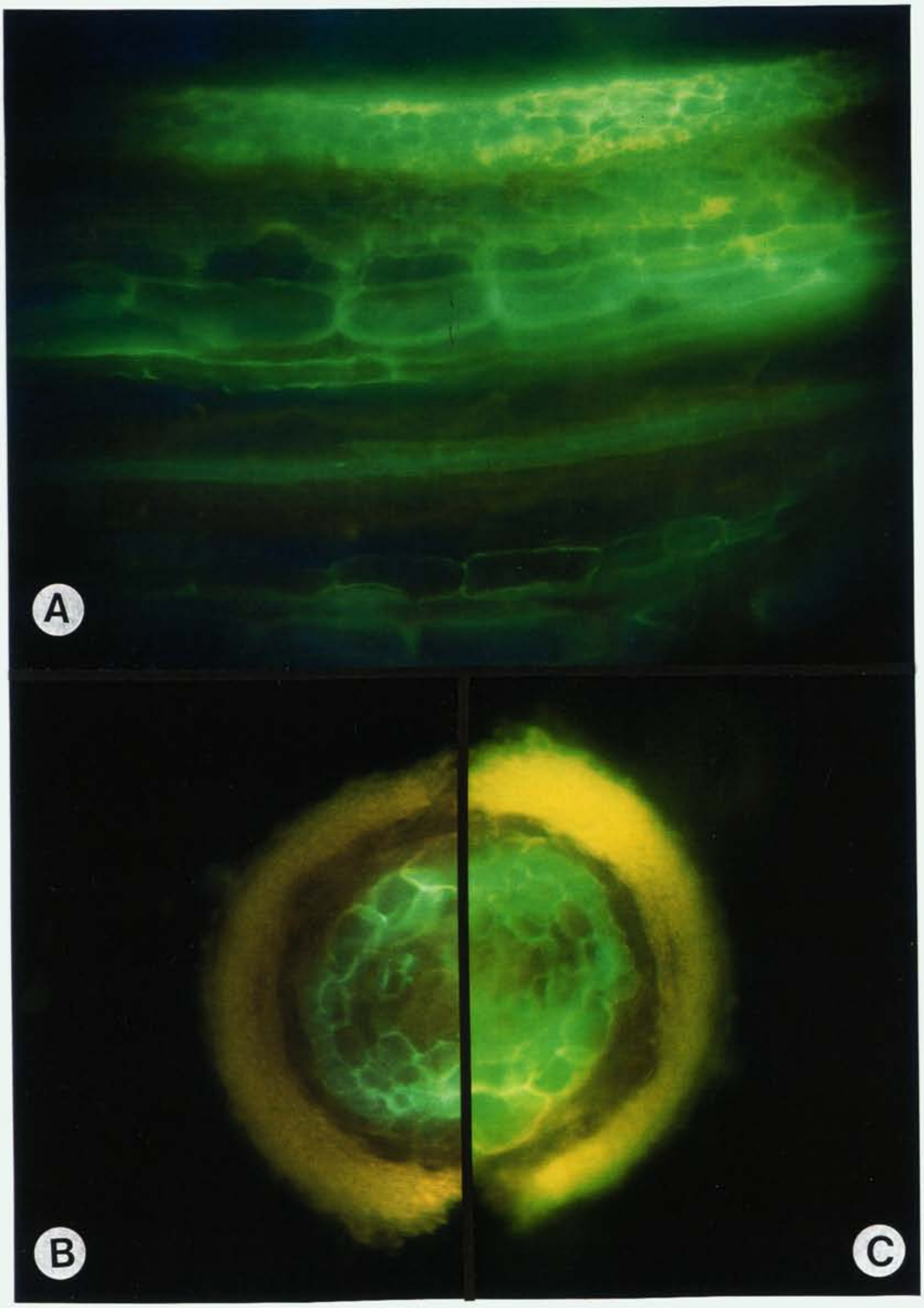


Figure 12-42A: *Tuber melanosporum* autofluorescence > 5 mm from tip, Unlimed. Outer mantle is bright blue with some traces of yellow in the inner regions while the Hartig net is orange to green. The large cortical cells are green-blue and the elongated endodermal and pericycle layers are bright green. The phloem on either side of the green xylem is very dull orange to non-fluorescent. Probe 8NA from unlimed soil at 0-10 cm depth. Lx. 400x. Photo 34-21, clear filter, 60 second exposure.

Figure 12-42B: *Tuber melanosporum* autofluorescence < 1 mm from tip, Limed. The mantle is distinctly dull yellow close to the tip in stark contrast to the intense blue of the unlimed probes. The Hartig net are here is poorly developed but is relatively non-fluorescent to very dull orange- yellow in contrast to the intense blue cortical cells. The phloem is dull orange. Probe 10K from limed soil at 0-10 cm depth, spring 2000. Cx. 400x. Photo 33-34, clear filter, 15 second exposure.

Figure 12-42C. *Tuber melanosporum* with Morin, < 1 mm from tip, Limed. The mantle has strong indications of aluminum in some regions but not others. The Cortical cells have some aluminum in the outer walls while the majority of cortical cells fluoresce weakly green indicating lesser Al in those regions. Probe 10K from limed soil at 0-10 cm depth, spring 2000. Cx. 400x. Photo 34-9, clear filter, 30 second exposure, 5 minutes after treatment.

12-42



Appendix 12-43: Tuber mesentericum

Fruiting body Occurrence: None

Mycorrhizal Occurrence: Rare. *Tuber mesentericum* was isolated in the fall 2000 from 0-10 cm depth in both unlimed and limed soil. In unlimed soil it was absent in spring 1999, present only at 50-60 cm depth in fall 1999, strongly present at 30-40 cm depth in spring 2000 and somewhat abundant in fall 2000. In limed soil it was present strongly in spring 1999 at both 0-10 and 30-40 cm depths, and weakly present in spring 2000 but otherwise absent implying a lack of drought recovery (Appendices 7-43 and 8A-B3-55).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 88. (Figure 43-A)

Fungal Autofluorescence: In unlimed soil the outer mantle and hyphae were faint yellow-green in fluorescence while in limed soil they were faint blue-green to green. The Hartig net cells were faint orange in both cases.

Root Autofluorescence: Typical blue.

Fungal Aluminum: In unlimed soil aluminum was present in the outer mantle and emanating hyphae but only in very low amounts as evidenced by the very slow reaction to Morin. In limed soil, aluminum was very strongly present in the mantle and hyphae (fast reaction time). In both cases the Hartig net cells were Al-free.

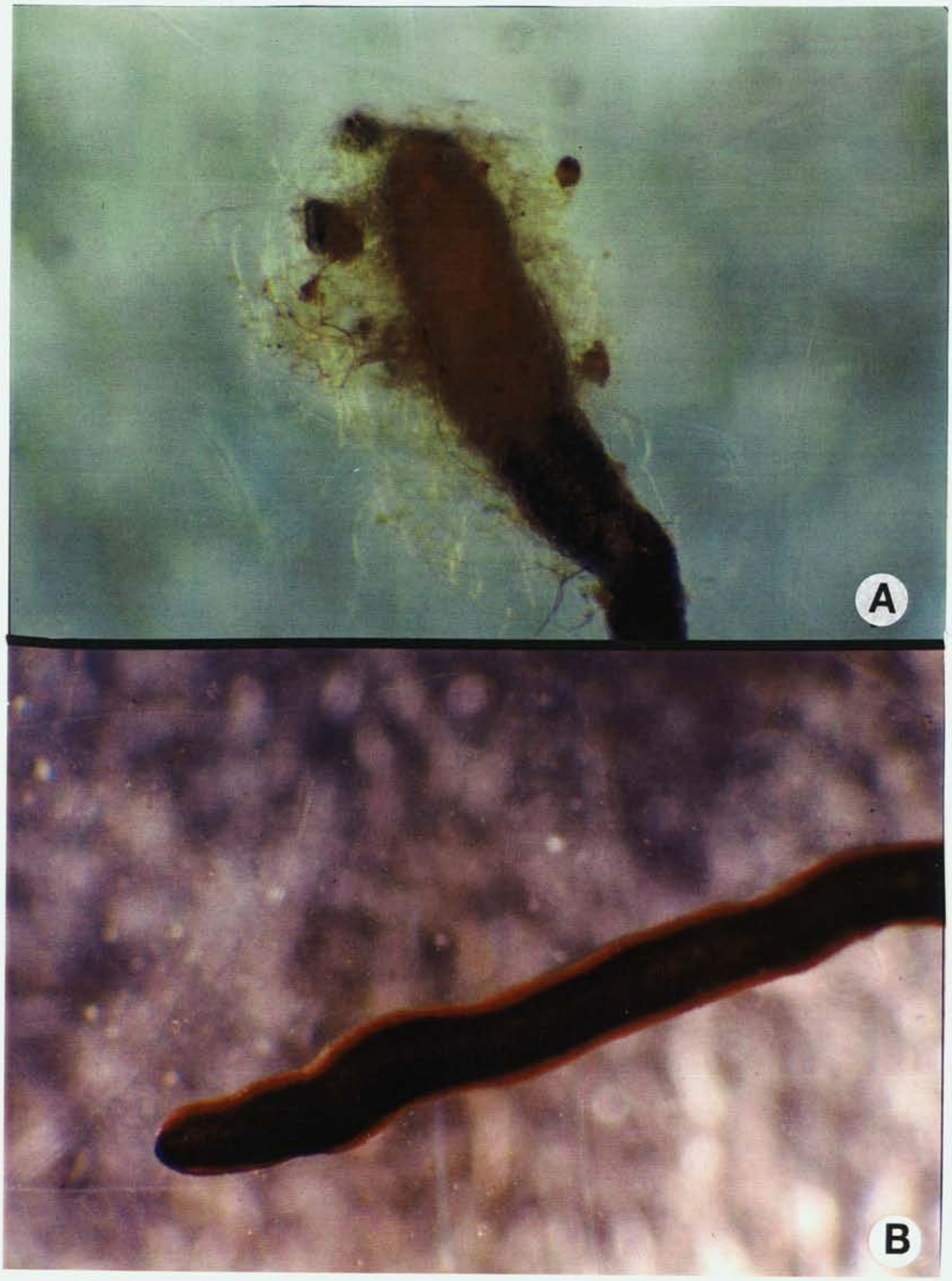
Root Aluminum: In unlimed soil the xylem was variably Al-free to slightly present and the cortical walls had small amounts of aluminum. In limed soil, Al was strongly present in the xylem and cortex.

Summary: In limed soil *Tuber mesentericum* promoted sequestration of aluminum in its outer mantle and hyphal cells and also was associated with enhanced translocation and sequestration within the cortical and xylem. In unlimed soil, significantly less aluminum was sequestered in the mantle, hyphae, xylem and cortex but that does not eliminate the possibility of enhanced translocation.

Figure 12-43A: ***Tuber mesentericum*** **gross morphology.** Single, unramified, club-shaped tip extending from darker "neck". Very long brownish cystidia forming a loose veil system over the mycorrhiza with adhering debris. Probe 200K from limed soil at 0-10 cm depth, spring 2000. 320x. Photo 7-27.

Figure 12-43B: ***Tuber rufum*** **gross morphology.** Single rufus (red) colored, slightly wavy, tip of a ramified mycorrhizal system (not shown). Probe 400N from unlimed soil at 0-10 cm depth, spring 2000. 110x. Photo 6-5.

12-43



Appendix 12-44: Tuber puberulum

Fruiting body Occurrence: None at Merzalben

Mycorrhizal Occurrence: *Tuber puberulum* was isolated primarily from limed soil at 0-10 cm depth, being weak in spring 1999, strongly present during the drought and the spring of 2000 and weakly presesent fall 2000. In limed soil it was also rarely found at 30-40 and 50-60 cm depth. In unlimed soil it was very weakly present at 0-10 cm depth in spring 1999 and fall 2000 only. (Appendices 7-44 and 8A-B3-56).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 22. Typical. (Figure 12-44A, 44B, and 44C).

Fungal Autofluorescence: The cystidia and emanating hyphae are intensely yellow while the mantle is faint yellow-green in fluorescence. The hartig net cells were blue. (Appendix 12 - 44D).

Root Autofluorescence: Typical (Figure12 - 44D).

Fungal Aluminum: Aluminum was definitely present in the cystidia but questionably present in the emanating hyphae. The mantle had a two-tone appearance with the outer regions containing aluminum while the inner regions did not. Aluminum was evident in the epidermal region of the Hartig net and more strongly so in the hypodermal regions of the Hartig net (Figure 12 - 44E).

Root Aluminum: The xylem strongly contained aluminum and specks of aluminum. The cortex contained aluminum throughout but with more intensity near the endodermal barrier (Figure 12 - 44E).

Summary: No comparisons to unlimed probes were possible, however there was strong sequestration in cystidia and translocation of aluminum to the cortex and xylem where it was abundant in the limed samples available.

Figure 12-44A: ***Tuber puberulum*** **cystidia.** Typical cystidia > 5 mm from tip showing straight hyaline bristles. Probe 1000K from limed soil 30-40 cm depth. Lx. 400x. Photo 18-24, white light, 1 second exposure.

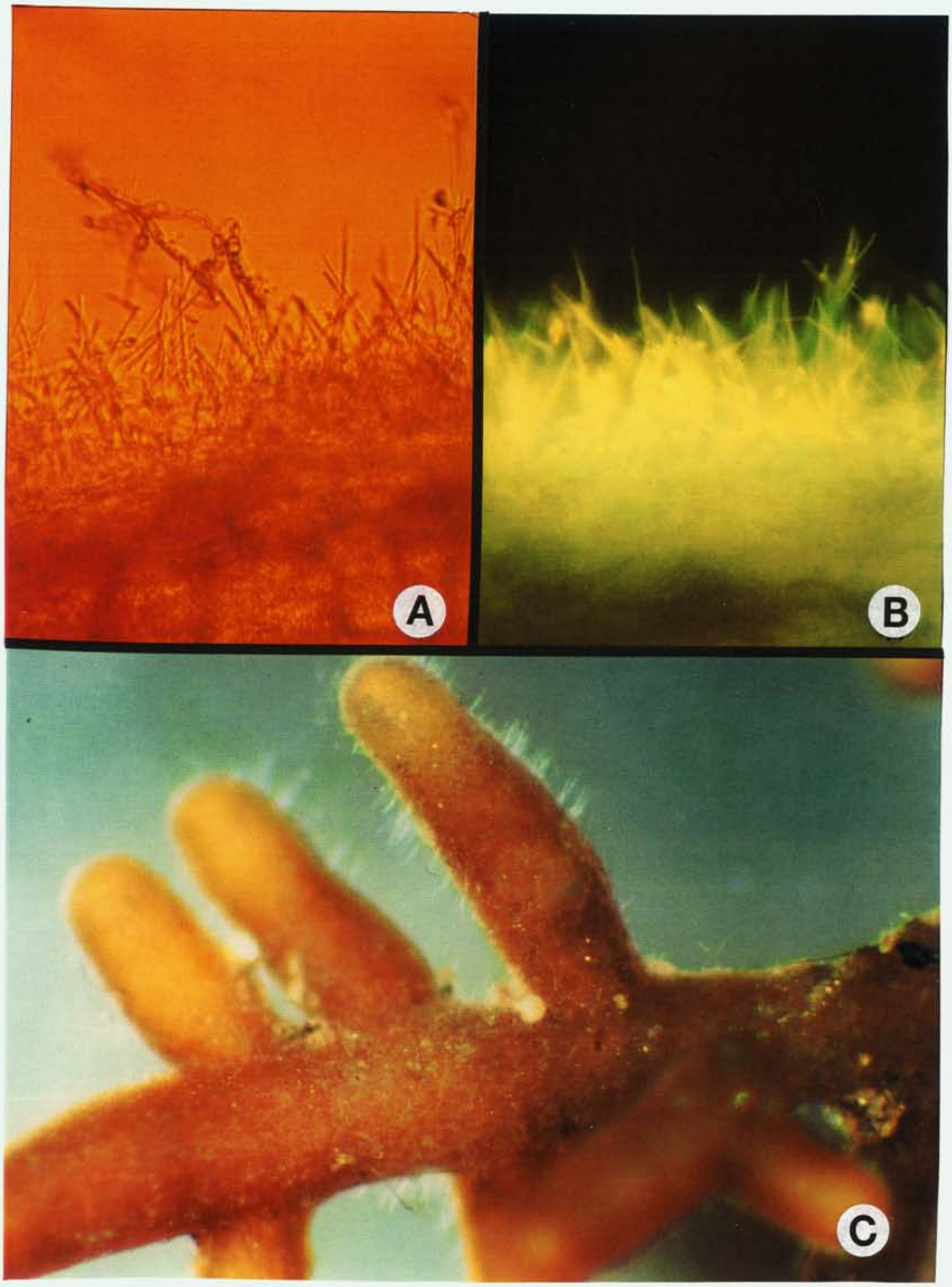
Figure 12-44B: ***Tuber puberulum*** **cystidia with Morin.** Cystidia > 5 mm from tip exhibit strong Morin reaction indicating abundant aluminum content. Probe 1000K from limed soil 30-40 cm depth. Lx. 400x. Photo 18-27, clear filter, 15 second exposure, 5 minutes after treatment.

Figure 12-44C. ***Tuber puberulum*** **gross morphology.** Portion of simple pyramidally shaped, branched, mycorrhizal system showing cystidia bristles emanating from the mantle. Probe 1000K from limed soil at 0-10 cm depth. Whole mount. 250x. Photo 2-37.

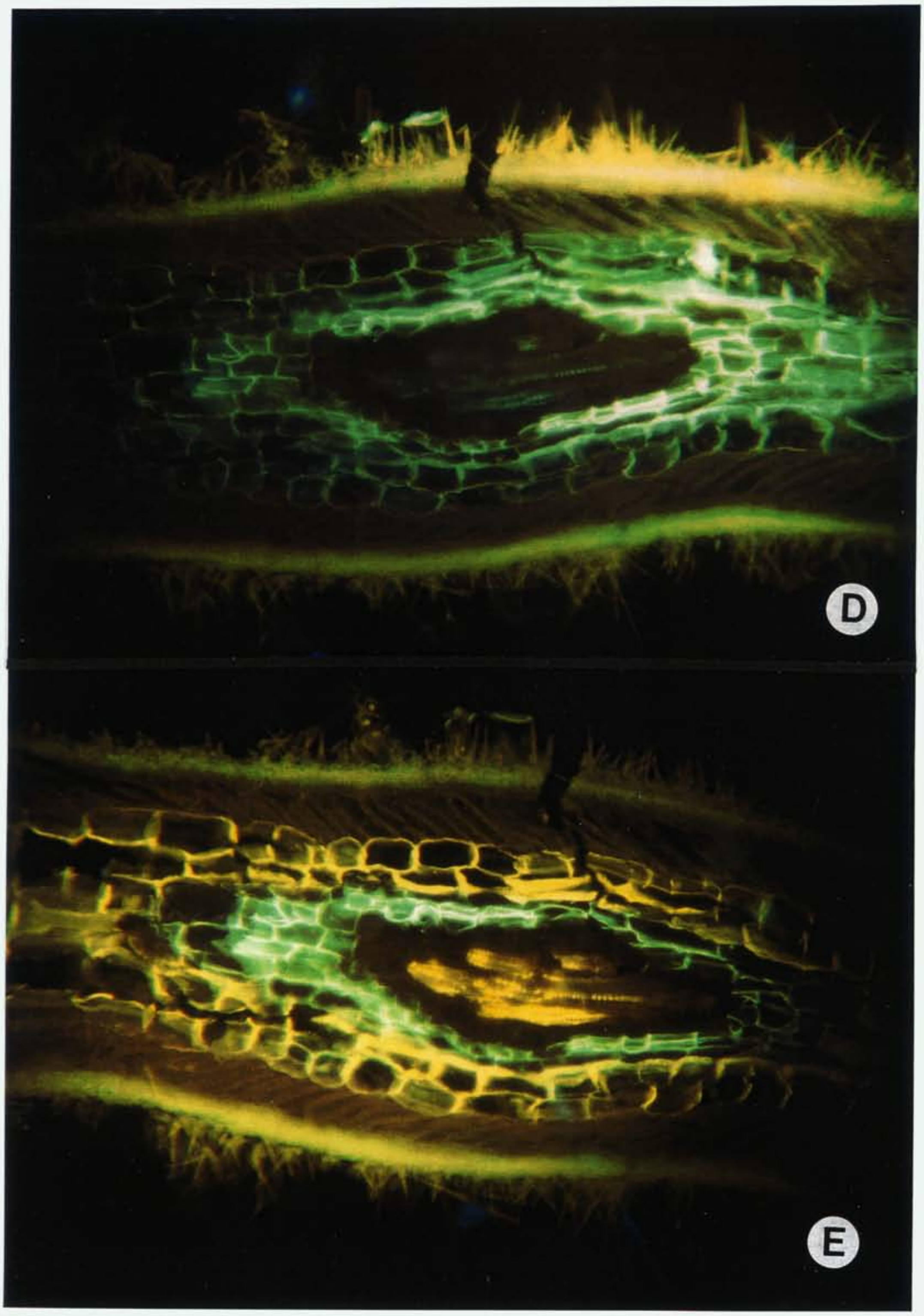
Figure 12-44D: ***Tuber puberulum*** **autofluorescence > 5 mm from tip.** The cystidia are very bright in natural fluorescence compared to the mantle which tended to be yellow-green and the Hartig net which was pale orange. The inner root cells fluoresced typical blue. The phloem was non-fluorescent. Probe 1000 K from limed soil at 30-40 cm depth in spring 2000. Lx. 250x. Photo 19-2, clear filter, 15 second exposure.

Figure 12-44E: Tuber puberulum with Morin > 5 mm from tip. The cystidia became deeper orange-yellow with Morin, while the mantle cells became brighter green to yellow green and the Hartig net remained unchanged. The cortical and xylem regions became extremely yellow while the two barrier layers (endodermal & pericycle) were unchanged. The disruption (due to sectioning) of the mantle and cortex seen in the top center of the section did not affect the aluminum reactions. Same section as in Figure 12-44D. Probe 1000K from limed soil at 30-40 cm depth in spring 2000. Lx. 250x. Photo 19-3, clear filter, 15 second exposure, 15 minutes after treatment

12-44



12-44



Appendix 12 - 45: Tuber rufum

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Tuber rufum* was present at 0-10 cm depth from spring 1999 to fall 2000 in both the unlimed and limed soils but it was most common in the spring 1999 in both with greater numbers in the unlimed soil (Appendices 7-24 and 8A-B3-57).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 89. Species confirmation based upon gross morphology, rufus color, and puzzle-like interlocking shapes of epidermoid cells in mantle in surface and cross-sectional views. (Figure 12-43B)

Fungal Autofluorescence: In unlimed soil the mantle cells were pale orange-yellow to orange-green to two-toned orange (inner) and pale yellow (outer). In limed soil, the mantle cells were more often two-toned with the inner regions being orange while the outer regions were pale yellow, yellow-green, pale green-yellow and where hyphae were present they were yellow to yellow-green. The Hartig net cells were primarily pale orange in both cases. (Figure 12-45A). At the root tips in the meristematic zone, the mantle was more intensely yellow- orange in the outer area, moderate in the middle, and more intensely yellow- orange in the inner mantle regions and while the Hartig net was poorly developed, it had a moderate orange autofluorescence. (Figure 12- 45C).

Root Autofluorescence: Typical, except that the cortical cells were frequently blue-green instead of pale blue in both unlimed and limed probes. In one unlimed probe the cortex was pale greenish-yellow. The mycorrhizae may affect chemical deposition in the cortical cell walls especially in dry soil. (Figures 12-45A). The root cells were more greenish in autofluorescence near the tip and the actual meristem region was orange-green (Figure 12-45C)

Fungal Aluminum: In the unlimed *Tuber rufum* probes, aluminum was more weakly present in the outer mantle cells as indicated by slower, more moderate color changes. In limed probes, aluminum varied from being absent (spring 1999) to strongly present (fall 1999, spring 2000) especially in the more distal cells. In both cases the Hartig net was mainly Al-free except for a questionable presence in unlimed samples in spring 1999 and in the meristematic zones. (Figure 12-45B) There was slow, low accumulation of aluminum evident nearer the tip (Figure 12-45D).

Root Aluminum: In unlimed probes, the xylem was variably free of aluminum (spring 2000) to containing small amounts and while the cortex generally had stronger reactions, in the spring 2000 it was also AL-free. In the spring 1999 some Al was present in the phloem walls, at the same time Hartig net also contained Al. In limed probes, the xylem was weak to strong in Al content, while the cortex generally had stronger reactions. Unlike the unlimed probes, in the limed samples, the cortex contained aluminum in the spring 2000 which corresponded to strong aluminum responses in the mantle cells during the same time period. (Figure 12-45B) There was stronger aluminum accumulation in, and near, the meristem than elsewhere in the root (Figure 12-45D).

Summary: *Tuber rufum* affected cortical cell wall depositions changing their natural fluorescence in both unlimed and limed samples close to the root tips but not in distal regions. Both unlimed and limed samples were similar in the sites of aluminum deposition and both had greater fall deposits, however, in the unlimed samples, less total aluminum accumulation was evident.

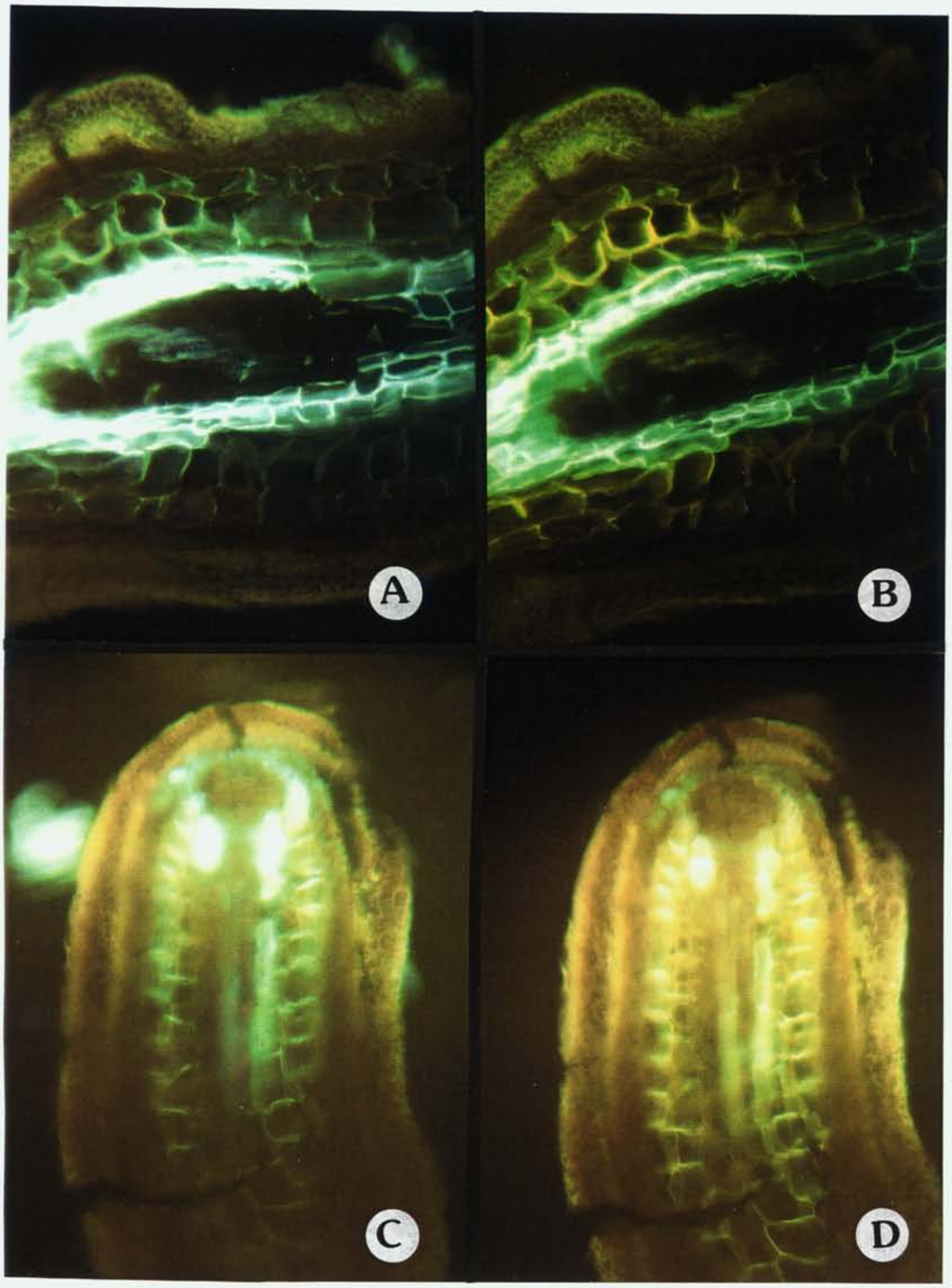
Figure 12-45A: *Tuber rufum* autofluorescence > 5 mm from tip. The outer mantle is yellow-orange with three regions, the outer most being bright, middle dull and innermost also being bright. The Hartig net is dull orange. The cortical cells fluoresced green-blue while the endodermal and hypodermal cells were bright blue. In the central cylinder the phloem was non-fluorescent while the xylem was blue. Probe 7 NA from unlimed soil 0-10 cm depth, fall 1999. Lx. 250x. Photo 36-16, clear filter, 40 second exposure.

Figure 12-45B: *Tuber rufum* with Morin > 5 mm from tip. The outer mantle is slightly greener but the cortex is definitely yellow with aluminum. The endodermis and pericycle are slightly greener indicating minimal Al but the xylem was beginning to take on a slight yellowish cast. Probe 7NA from unlimed soil 0-10 cm depth, fall 1999. Lx. 250x. Photo 35-21, clear filter, 60 second exposure, 4 minutes after treatment.

Figure 12-45C: *Tuber rufum* autofluorescence < 1 mm from tip. The outer mantle is more distinctly yellow-orange near the very tip with three distinct layers, outer bright, middle dull, inner bright. Immediately interior to the mantle is the Hartig net which is also more intense but still dull orange than in more mature regions of the mycorrhizal tip. The meristem is evident at the very tip as an oval orange-green region surrounded by cortical cells which are more green than blue in autofluorescence with some yellow-orange regions immediately lateral to the central cylinder zone at the tip. Probe 400N from unlimed soil at 0-10 cm depth in spring 2000. Lx. 250x. Photo 35-17, clear filter, 30 second exposure.

Figure 12-45D: Tuber rufum with Morin < 1 mm from tip. The outer mantle area is primarily duller indicating no aluminum uptake, but fluorescence loss due to increased fluid underneath the coverslip and diffraction of the light. Some lateral mantle areas show more intense fluorescence indicating some lateral accumulation of Al. The Meristem zone is more pronounced orange and all the root cells at the tip exhibit aluminum content, but less than 0.5 mm from the tip, the aluminum content is considerably lower. Probe 400N from unlimed soil at 0-10 cm depth in spring 2000. Lx. 250x. Photo 35-24, clear filter, 60 second exposure, 7 minutes after treatment.

12-45



Appendix 12-46: Tomentella ferruginea

Fruiting body Occurrence: None

Mycorrhizal Occurrence: *Tomentella ferruginea* was present primarily in fall 2000 at 0-10 cm depth in both unlimed and limed soils. It was slightly more common in limed soils. It made appearances at 0-10 cm depth in spring 1999 (limed) and fall 1999 (unlimed) but otherwise was rare (Appendices 7-46 and 8A-B3-53).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 137. Confirmation of species determined by mycorrhizal gross morphology and specifically the rhizomorphs, both of which had a dense veil of, twisted, emanating hyphae (Figure 12-46C).

Fungal Autofluorescence: In both unlimed and limed soil, the outer mantle and emanating hyphae were non-fluorescent. In unlimed soil, the hartig net cells were faint orange while in limed soil the cells varied from non-fluorescent (fall 1999) to faint yellow or orange (0-10 cm depth, fall 2000) to green (50-60 cm depth, fall 2000). (Figure 12-46A)

Root Autofluorescence: Typical except in the limed probes, fall 2000 at 50-60 cm depth, where the cortical cells fluoresced orange. In unlimed probes, the phloem was faint orange, cortical cells were yellow-blue, while the xylem, pericycle and endodermis fluoresced blue. (Figure 12-46A)

Fungal Aluminum: The unlimed mycorrhizae were Al-free. In limed soil, the outer mantle cells were Al-free except for specks present at 50-60 cm depth and while the hartig net cells were Al-free in fall 1999, in fall 2000 aluminum was present in all samples. (Figure 12-46B)

Root Aluminum: In unlimed probes, Al was equally present in the xylem and cortex but there was a questionable presence in the pericycle, endodermis and phloem. In the limed probes Al was present in the xylem and cortex and often in the hartig net. Where Al was strongly present in the hartig net, it was weaker in the cortex and stronger in the xylem. Where Al was weak in the hartig net, it was more evident in the cortex and weaker in the xylem. (Figure 12-46B).

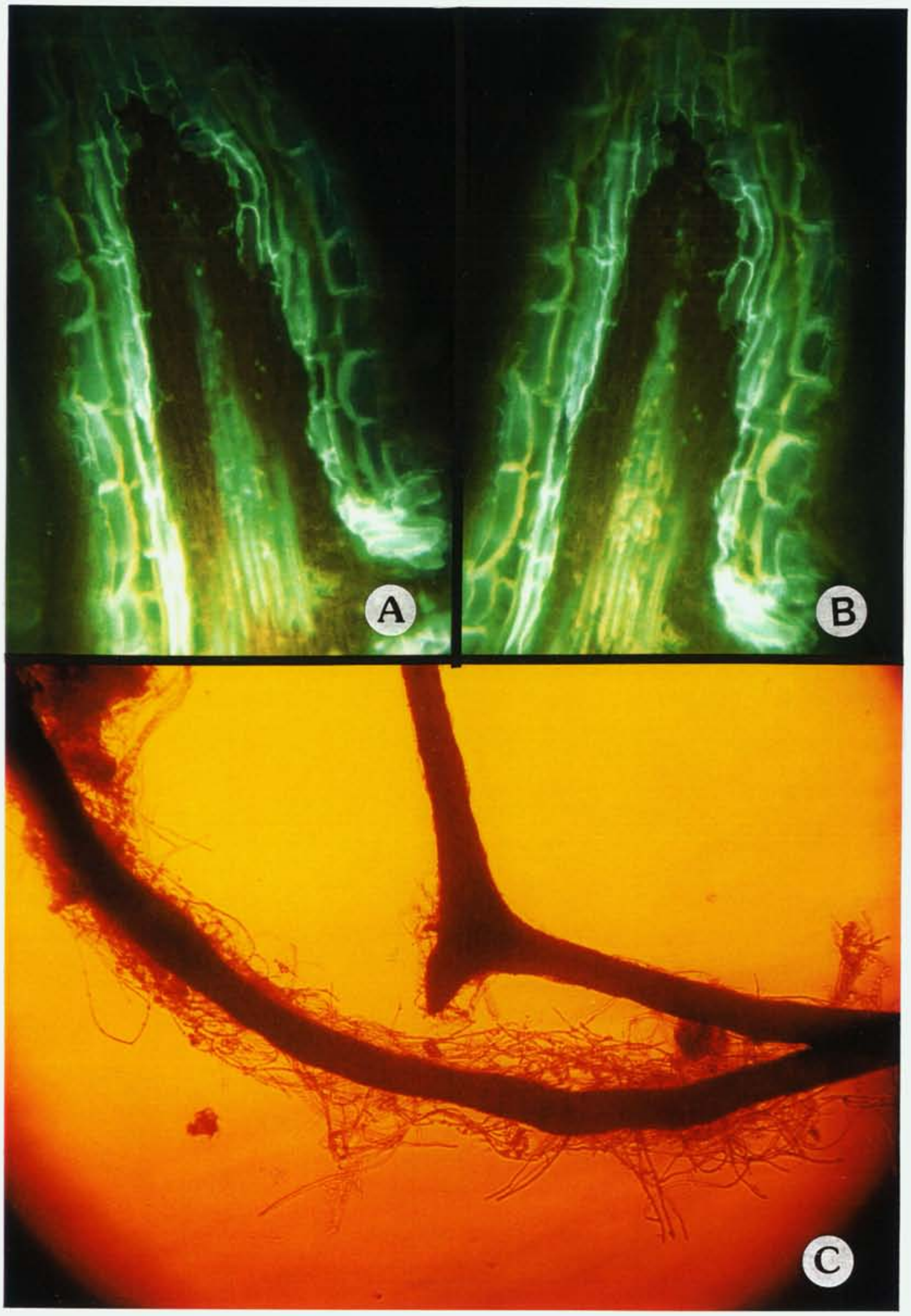
Summary: In unlimed soil, the mycorrhizal did not sequester Al nor stop its translocation, but in limed soil, the mycorrhizal mantle was variably effective in altering Al translocation into the root.

Figure 12-46A: ***Tomentella ferruginea*** **autofluorescence > 5 mm from tip.** The mantle is non-fluorescent but the cortical and xylem fluoresce green with some deep yellow areas evident in the cortical walls. The phloem is dull orange and the endodermis and pericycle are bright blue. Probe 8NA from unlimed soil at 0-10 cm depth in fall 1999. Lx. 250x. Photo 37-2, clear filter, 60 second exposure.

Figure 12-46B: ***Tomentella ferruginea*** **with Morin > 5 mm from tip**. The roots appear to be the same at first glance but the Morin has produced yellow colorations in regions other than the areas evident in natural fluorescence indicating some aluminum irregularly accumulating in thick cortical walls and in the xylem in spots but not in the mantle. Probe 8NA from unlimed soil at 0-10 cm depth in fall 1999. Lx. 250x. Photo 37-3, clear filter, 60 second exposure.

Figure 12-46C: ***Tomentella ferruginea*** **Rhizomorph**. Typical rhizomorph used for species confirmation. Notice the network of loose hyphae around the solid central rhizomorph. Probe 8N from unlimed soil at 0-10 cm depth, fall 1999. 160x. Photo 36-35.

12-46



Appendix 12-47: Xerocomus chrysenteron

Fruiting body Occurrence: Spring 2000, unlimed soil only, rare to common.

Mycorrhizal Occurrence: Very common at 0-10 cm depth. *Xerocomus chrysenteron* was present in both unlimed and limed soil all seasons except for the very dry fall 1999 when it was absent from the limed samples. It was most common in spring 2000 in the unlimed soil at 0-10 cm depth followed by fall 2000. In limed soil it was most frequently found in fall 2000 at 0-10 cm depth. At 30-40 cm and 50-60 cm depths it was rare in both zones. (Appendices 7-47 and 8A-B3-67).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 34. Typical. Very similar to *Xerocomus prunatus* (Figures 12 - 47A, 47B).

Fungal Autofluorescence: The outer mantle and rhizomorph usually fluoresced pale yellow while the Hartig net cells were pale orange to pale yellow. In unlimed soil the individual rhizomorphs ranged in fluorescence from blue to orange-yellow to yellow-orange to pale yellow to yellow; while in limed soil they ranged from blue to pale blue-green to pale yellow-green to pale yellow. But in all cases there was an overall pale yellow dominant tinge. The mantle cells were more consistently pale yellow but in one probe (spring 1999, unlimed soil 0-10 cm depth) the mantle cells had an orange cast and in the same probe the Hartig nets cells ranged from blue to pale yellow instead of pale orange. In fall 2000 at 0-10 cm depth in unlimed soil the Hartig net cells were non-fluorescent while in limed soil they were very pale yellow. (Figures 12 - 47C, 47E, 47F).

Root Autofluorescence: Typical for all limed samples. Typical for unlimed roots except at 0-10 cm depth where the cortex was yellow-blue (spring 1999), orange (fall 1999), and non-fluorescent or green (fall 2000) and in the spring 2000 when the phloem cells were faint orange in fluorescence (Figure 12 - 47C).

Fungal Aluminum: The mantle, hyphal and Hartig net cells usually remained the same or lost fluorescence becoming paler. At 0-10 cm depth, in spring 2000 some aluminum was evident in the unlimed rhizomorphs and the some limed mantle cells; while in the fall 2000 aluminum was definitely present in the unlimed rhizomorphs and mantle cells, in the limed probes it was only present in the rhizomorphs (Figure 12 - 47D, 47G). At 30-40 cm depth Al was questionably present in the unlimed mycorrhizal cells. The majority of the time, the unlimed and limed mycorrhizae were Al-free.

Root Aluminum: In unlimed probes at 0-10 cm depth, the xylem contained aluminum, while the cortical cells (except for spring 2000) were Al-free. In some cases aluminum was present in the endodermis (old roots, spring 1999) and phloem (> 5 mm, spring 2000) and questionable green pigmentation was evident in endodermal, cortical and Hartig net cells (old roots, fall 2000). At 30-40 and 50-60 cm depth aluminum was present in the xylem and variable in the cortex. At 30-40 cm aluminum was present in some phloem cells. In limed probes at all depths, the xylem and cortical cells contained aluminum with the strongest concentrations occurring at 0-10 cm depth, fall 2000 (Figure 12 - 47D).

Summary: More aluminum was translocated to and sequestered by roots grown in limed soil. In both unlimed and limed plots, the highest aluminum concentrations in the mantles occurred in the fall 2000 but in the case of the unlimed probes, less Al was evident in the xylem and cortex while in the limed probes, more Al was present in the root. *Xerocomus chrysenteron* does not tend to sequester aluminum in its cell walls unless adequate moisture is present. In limed soil, in the presence of *Xerocomus chrysenteron,* more aluminum is sequestered in the cortical cells.

Figure 12-47A: *Xerocomus chrysenteron* morphology - unlimed soil. Small monopdal pinnate tree in foreground with thin rhizomorph emanating from base and extending below and behind the tree. Mantle has silvery appearance due to trapped air. Probe 100 N from unlimed soil at 0-10 cm depth, spring 2000. 125x. Photo 3-22.

Figure 12-47B: *Xerocomus chrysenteron* morphology - limed soil. Single, small monopodal pinnate tree with thick rhizomorph emanating from base and extenting to the right. Probe 100 N from limed soil at 0-10 cm depth. 70x. Photo 1-11.

Figure 12-47C: *Xerocomus chrysenteron* autofluorescence > 5 mm from tip. Outer mantle (top) was pale green while the hartig net was orange. The cortex was dull blue, the endodermis and pericycle were very bright blue and the xylem (bottom) was very faint blue. Probe 200 N from unlimed soil 30-40 cm depth. Lx. 400x. Photo 27-28, clear filter, 90 second exposure.

Figure 12-47D: *Xerocomus chrysenteron* with Morin > 5 mm from tip. Same section as in Figure 47C. Mantle and Hartig net faded while the root cell walls became intensely bright green. Lx. 400x. Photo 27-29, clear filter, 90 second exposure, 5 minutes after treatment.

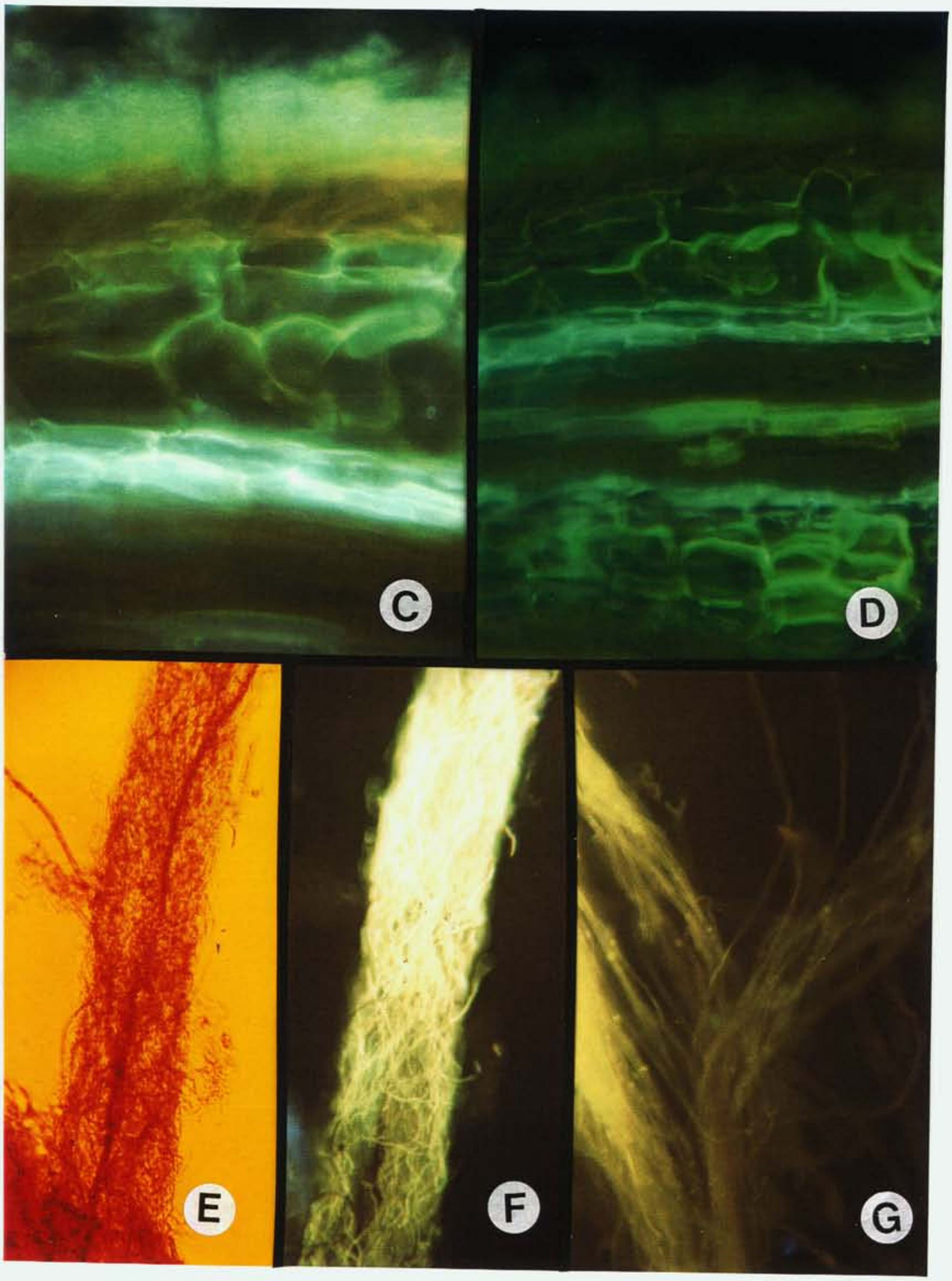
Figure 12-47E: *Xerocomus chrysenteron* Rhizomorph. Under the compound microscope, in incandescent light, the rhizomorph appears reddish. Probe 4K from limed soil at 0-10 cm depth in spring 1999. 250x. Photo 27-32, 2 second exposure.

Figure 12-47F: *Xerocomus chrysenteron* Rhizomorph autofluorescence. Same rhizomorph as in Figure 47E appears bright, light yellow in UV. 250x, Photo 27-33, clear filter, 60 second exposure.

Figure 12-47G: *Xerocomus chrysenteron* Rhizomorph after freezing and staining. Freezing disrupted the helixed nature of the rhizomorph, denaturing and relaxing the integrated hyphal strands. The rhizomorphs however stained with Morin gave relatively the same increase in intensity in deep yellow color indicating the strong presence of aluminum within the rhizomorphs frozen or not. Probe 4K from limed soil 0-10 cm depth in spring 1999. 400x. Photo 27-37, clear filter, 60 second exposure, 5 minutes after staining.

12-47

12-47



Appendix 12-48: Xerocomus submentosus

Fruiting body Occurrence: None in Merzalben.

Mycorrhizal Occurrence: Rare. *Xerocomus submentosus* was isolated from 0-10 cm depth in spring 2000 in both unlimed and limed areas. It was most prevalent in unlimed soil. In unlimed soil the strongest showings were fall 2000 (50-60 cm depth) and spring 2000 (0-10 cm followed by 30-40 cm depths). Fewer tips were found in limed soil with the strongest showing at 0-10 cm depth in spring 2000 followed by fall 1999. Otherwise it was absent. (Appendices 7-48 and 8A-B3-68).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 90. The rhizomorphs were very intense yellow in natural light and the ectomycorrhizae were pale to golden yellow.

Fungal Autofluorescence: In both unlimed and limed soil, the mantle and rhizomorphs fluoresced very intense orange-yellow while the Hartig net cells were intense orange (Figure 12 - 48A, 48B).

Root Autofluorescence: Typical . (Figure 12 - 48A, 48B)

Fungal Aluminum: Aluminum was present only in the outer mantle cell walls in both cases. The unlimed mycorrhizal reactions were very slow, implying low amounts of aluminum while the limed mycorrhizae responded more quickly and bright green specks were also present , implying abundant aluminum (Figure 12 - 48C).

Root Aluminum: The unlimed roots were Al-free. The limed roots occasionally contained only variable amounts of aluminum in the cortical cells and no where else.

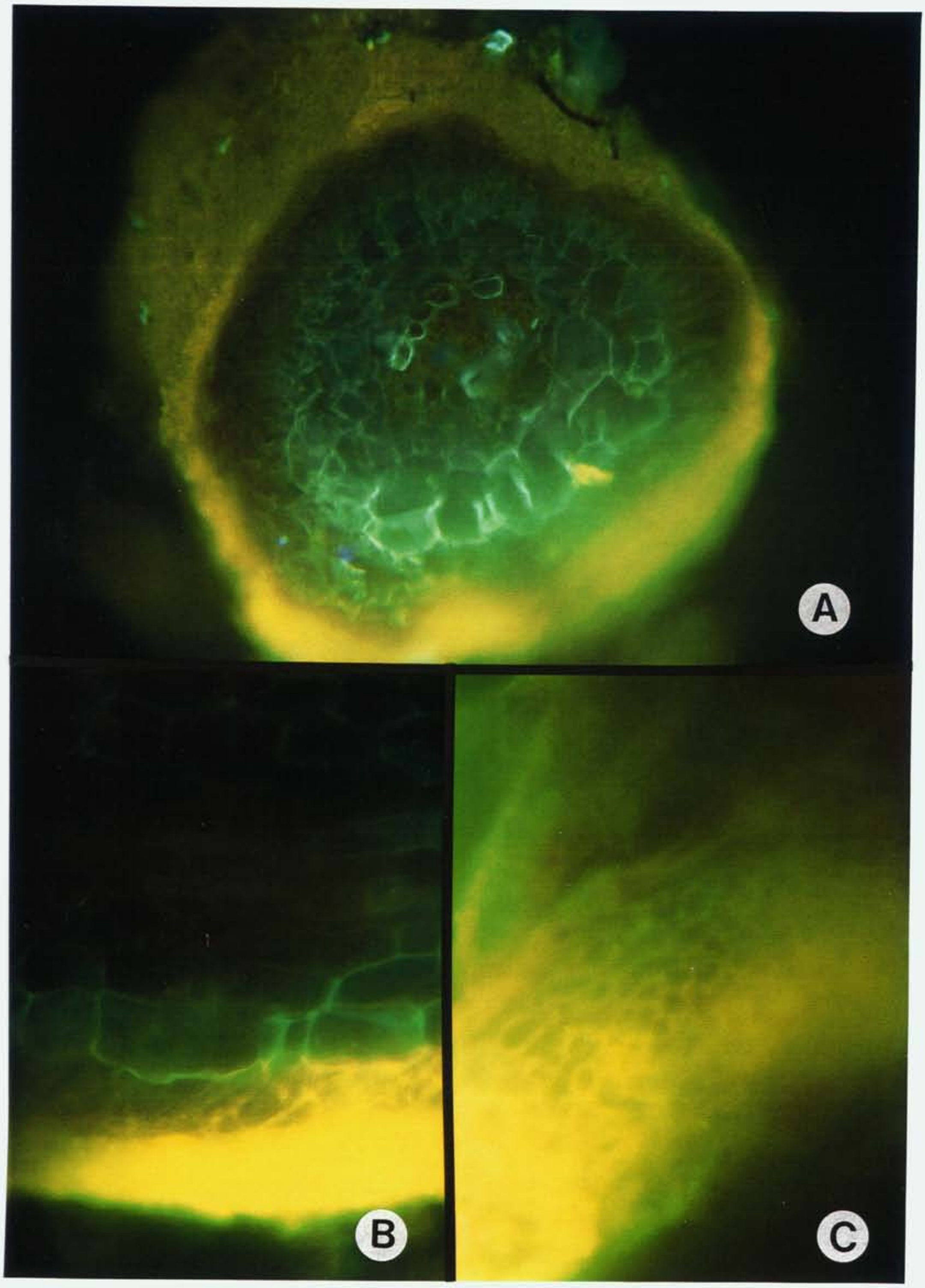
Summary: *Xerocomus submentosus* was effective at sequestering aluminum in its outer mantle cells leaving the root cells mostly aluminum-free. This rare mycorrhizae may be rare because of its ability to sequester aluminum.

Figure 12-48A: *Xerocomus submentosus* autofluorescence > 5 mm from tip. The mantle autofluoresced bright orange-yellow while the Hartig net was dull orange to non-fluorescent and the central root region was typically blue. Probe 100N from unlimed soil at 0-10 cm depth, spring 2000. cx. 400x. Photo 32-36, clear filter, 60 second exposure.

Figure 12-48B: *Xerocomus submentosus* autofluorescence < 1 mm from tip. The mantle and Hartig net were brighter orange-yellow closer to the tip. The cortical cells were blue. Probe 100N from unlimed soil at 0-10 cm depth, spring 2000. Lx. 400 x. Photo 32-35, clear filter, 30 second exposure.

Figure 12-48C: *Xerocomus submentosus* with Morin < 1 mm from tip. The mantle cells fluoresced more brightly yellow in the presence of Morin in most mantle areas and in addition, there were areas of bright green fluorescence both outside and in the inner mantle areas. The root cells remained blue. Probe 400K from the limed soil at 0-10 cm depth, spring 2000. Cx. 1000x. Photo 32-34, clear filter, 90 second exposure, 5 minutes after Morin treatment.

12-48



Appendix 12-49: Unknown Gray

Fruiting body Occurrence: Unknown

Mycorrhizal Occurrence: Rare. *Unkown gray* was isolated from both unlimed and limed soils from 0-10 cm depth in the fall 2000 only (Appendices 7-49 and 8A-B3-63).

Mycorrhizal Morphology: Not present in Agerer (1987-1998). Unramified simple ectomycorrhizal tips, often extending from old *Cenococcum geophilum* tips and seldom independently found on the fine roots. Up to 2 mm long with oblong shape 0.45 to 0.65 mm in diameter. Mantle was clear and woolly in nature with underlying swollen root tip visible. A few scattered dark - purple-reddish hyphae were visible through the clear hyphal mantle. It was unclear whether these were part of the Unknown Gray morphology or related to the adjacent *Cenococcum*. Occasionally clear long hyphal strands emanated from the mantle. Possibly and early stage of *Byssocorticium atrovirens ?* (Figure 12-49A).

Fungal Autofluorescence: In both unlimed and limed soils the mantles fluoresced green. The Hartig net was very pale blue (unlimed) or non-fluorescent (limed) (Appendix 7 - 49).

Root Autofluorescence: Typical.

Fungal Aluminum: Aluminum was present in outer mantle cells only in all tests.

Root Aluminum: In unlimed soil, Al was strongly present in the xylem and cortex, while in limed soil it was strong in the xylem but variable and questionable in the cortex.

Summary: The unknown gray can sequester aluminum in its outer mantle regardless of liming but somewhat less aluminum seems to be translocated and sequestered in the limed roots.

Figure 12-49A: Unknown Gray. Unknown Gray tip with clear woolly mantle containing purple-red hyphae visible through the mantle and a few long, clear emanating hyphae. Unknown Gray tip is growing from an old *Cenococcum geophilum* tip. Probe 400N from unlimed soil at 0-10 cm depth, spring 2000. 320x. Photo number 7-23.

Figure 12-49B: Unknown Rosa. Unknown Rosa is present here as rose-red tips and as retrograde growth extending backwards from the tips to the main root axis. The mantle forms a thick loose covering over the root with many air pockets and adhering sandy debris. In addition two black tips of *Cenococcum geophilum* are present with their long black emanating hyphae and one golden-yellowish tip of *Lactarius subdulcis* visible in the upper left quadrant. Probe 200K from limed soil at 30-40 cm depth, spring 2000. 125x. Photo 4-29.

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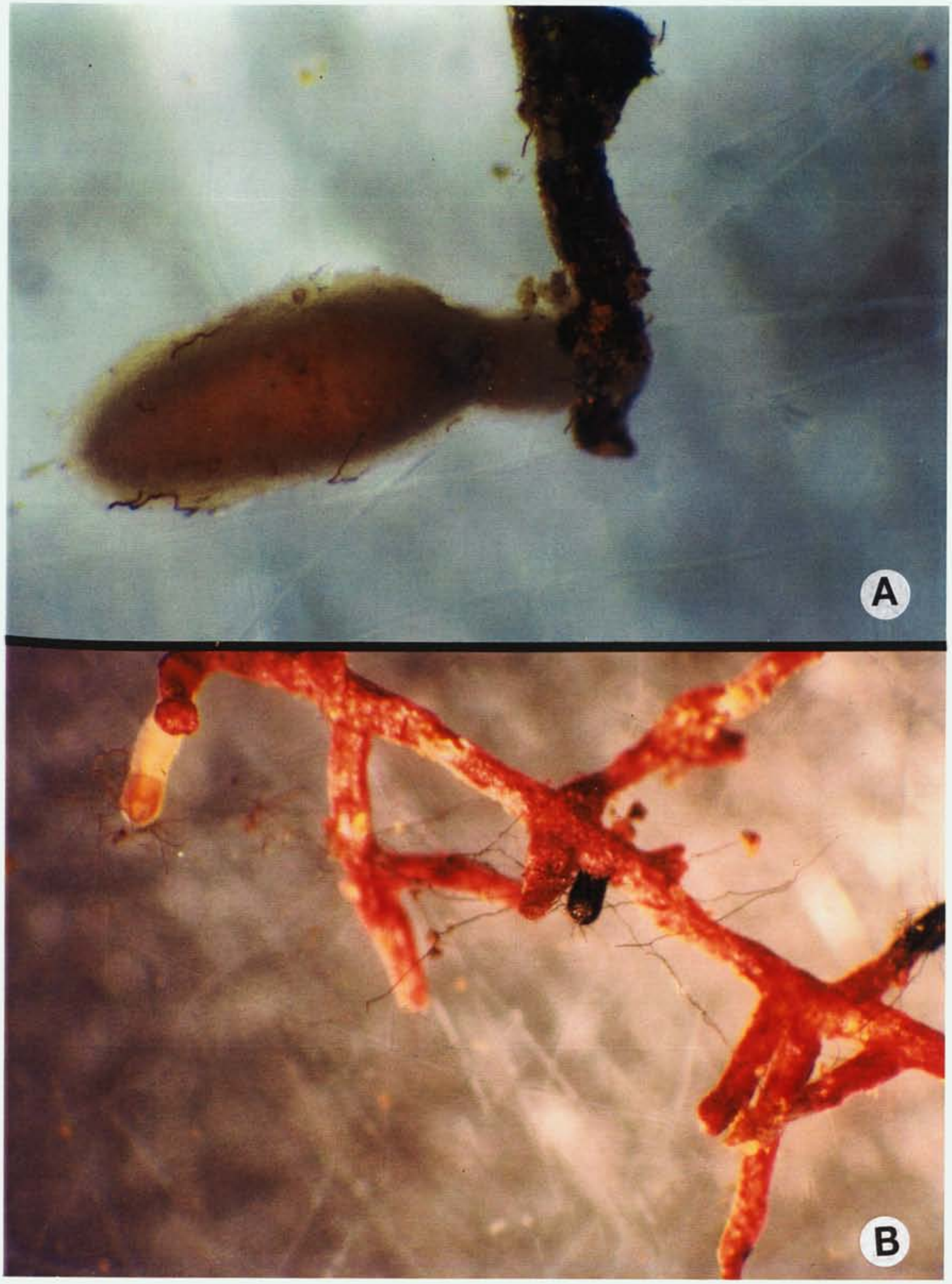

Appendix 12-50: Unknown Rosa

Fruiting body Occurrence: Unknown

Mycorrhizal Occurrence: Frequent. *Unknown Rosa* was first found in large numbers in spring 1999, but only in limed soil at 0-10 cm depth. It dissappeared during the dry fall 1999 but reappeared the following spring 2000 in unlimed soil probes at all soil depths in similar abundance. It was also present in the limed probes in spring 2000 at all depths (mostly at 30-40 cm) but in much lower frequency. In fall 2000 it was most common at 0-10 cm depth in unlimed soil, and less common 30-40 cm depth with a few rare tips at 50-60 cm. In limed soil in fall 2000 it was uncommon with the frequency was highest at 30-40 cm depth (Appendices 7-50 and 8A-B3-65).

Mycorrhizal Morphology: Not present in Agerer (1987-1998) - Identified by rosy color. Young tips have simple unramified ends straight to slightly bent with occasional bulbose ends, up to 4 mm long, 0.45 to 0.55 mm diameter. Outer mantle distinctive rosy colored, reticulate to grainy with air pockets and a few short spiny emanating hyphal tufts. No rhizomorphs were found. Rosy extensions first appear perpendicular to the root, but in older root regions (further from the root tips), the rosy - red mantle appears to spread in a retrograde fashion backwards over the root rather than extending from the root. In cross-section the mantles were wide but composed of loosely packed, non-fluorescent hyphae and the Hartig net extended beyond the epidermal and hypodermal areas into the intercellular cortical zone up to a delimiting cortical barrier of enlarged cells. The surface mantle was composed of plectenchymatous hyphae rather irregularily arranged with no special pattern but generally running longitudinally along the axis with some networking. The diameter of the young mantle cells was variable but the older mantle cells were smaller, more uniform and the mantle width at > 5 mm was less than 1/3 of that at < 1 mm from the tips. The Hartig net cells in the inner most cortical regions were collapsed in the older root regions along with their companion root cells with many air pockets but a viable strong cortical barrier was present internal to the former Hartig net zone. Long black hyphal extensions occasionally seen were more probably from the co-symbiont *Cenococcum geophilum*. Rosa was often associated with *Cenococcum geophilum* tips where it was found partly under the *Cenococcum* and extending backwards over the root surfaces to the axis and beyond. Long hyphae of *Cenococcum* could be seen growing through the Rosa mantle and emerging at distal loci. Debris was tightly adhesive but irregularily present and generally absent in older regions. (Figure 12 - 49B).

Fungal Autofluorescence: In unlimed soil the mantle and emanating hyphae of *Unknown Rosa* were non-fluorescent to blue while the Hartig net cells were orange (outer) to blue (inner). In limed soil, the mantle and hyphae non-fluorescent while the Hartig net cells were faint orange-yellow (outer) to blue (inner) (Figure 12 -50A, 50C)

Root Autofluorescence: Typical except at 30-40 cm depth where the phloem cells were often pale orange. (Figure 12 -50A, 50C)

Fungal Aluminum: In unlimed and limed probes the outer mantle and emanating hyphae were Al-free while the Hartig net cells all contained Al. In both cases, more Al was found in the younger tissues closer to the tips and in tips from deeper soil probes. In limed probes, emanating hyphae had yellow specks associated with them but were otherwise Al-free and the Hartig net contained more Al than comparable unlimed roots at 30-40 cm depth. (Figure 12 -50B 50D)

Root Aluminum: In unlimed soil, at 0-10 cm depth the xylem (strongly) contained Al as did some cortical cells near the pericycle and endoderm, while at 30-40 cm depth, the xylem (moderately) and cortex (strongly) contained Al in < 1 mm tip regions. In limed soil, the xylem was variably Al-free to strongly present and the cortex contained some aluminum implying better sequestration in the fungal mantle. Although the mantle was Al-free in unlimed soil, more Al was evident in the root and conversely, in limed soil, the mantle contained more Al but it was less evident in the root cells. (Figure 12 -50B, 50D)

Summary: In limed soil, even at 30-40 cm depth, the mycorrhizae were better able to sequester aluminum and control root Al uptake. In unlimed soil, despite sequestration in the Hartig net, more Al was translocated to the root cells.

Figure 12-50A: Unknown Rosa autofluorescence < 1 mm from tip. Mantle was non-fluorescent but Hartig net cells were faint orange-yellow in the external areas and greenish to fading blue in the internal zones which extended deep into the modified (smaller) cortical regions. The innermost, large cortical, endodermal (incomplete) and xylem cells were blue to bluish green. Phloem in the central cylinder was non-fluorescent. External adhering debris was blue to greenish blue to yellow. Probe 1100N from unlimed soil at 0-10 cm depth, fall 2000. 400x. Photo number 16-10A, clear filter, 30 second exposure.

Figure 12-50B: Unknown Rosa with Morin < 1 mm from tip. Same section as shown in figure 50A, after treatment. The mantle, outer Hartig net, endodermis and phloem were unchanged but the inner Hartig net, cortex, and xylem had more intense yellow fluorescence with the strongest reactions occurring in the walls of the innermost cortical cells and the xylem. The endodermal barrier was incomplete, allowing for natural access to the central cylinder and xylem. Spots in the external debris showed strong aluminum content. Probe 1100N from unlimed soil at 0-10 cm depth, fall 2000. 400x. Photo number 16-10B, clear filter, 30 second exposure.

Figure 12-50C: Unknown Rosa autofluorescence > 5 mm from tip. Mantle was non-fluorescent but older, outer Hartig net regions were deep orange-yellow while the inner former Hartig net areas (which had collapsed) were bright blue to yellow blue to green. The remaining root cells were intensely bright blue while the phloem was non-fluorescent or very faint orange. Adhering debris was non-fluorescent. Probe 1000K from limed soil at 30-40 cm depth, fall 2000. 400x. Photo number 18-11, clear filter, 15 second exposure.

Figure 12-50D: Unknown Rosa with Morin > 5 mm from tip. Same section as in Figure 50C, after treatment. The mantle and minor external debris were non-fluorescent. The region of the outer Hartig net was deeper orange and the area of the former Hartig net (now collapsed) was orange to bright yellow up to the large cortical cells. The interior root cells were aluminum free. Probe 1000 K from limed soil at 30-40 cm depth, fall 2000. 400x. Photo number 18-13, clear filter, 15 secondexposure.

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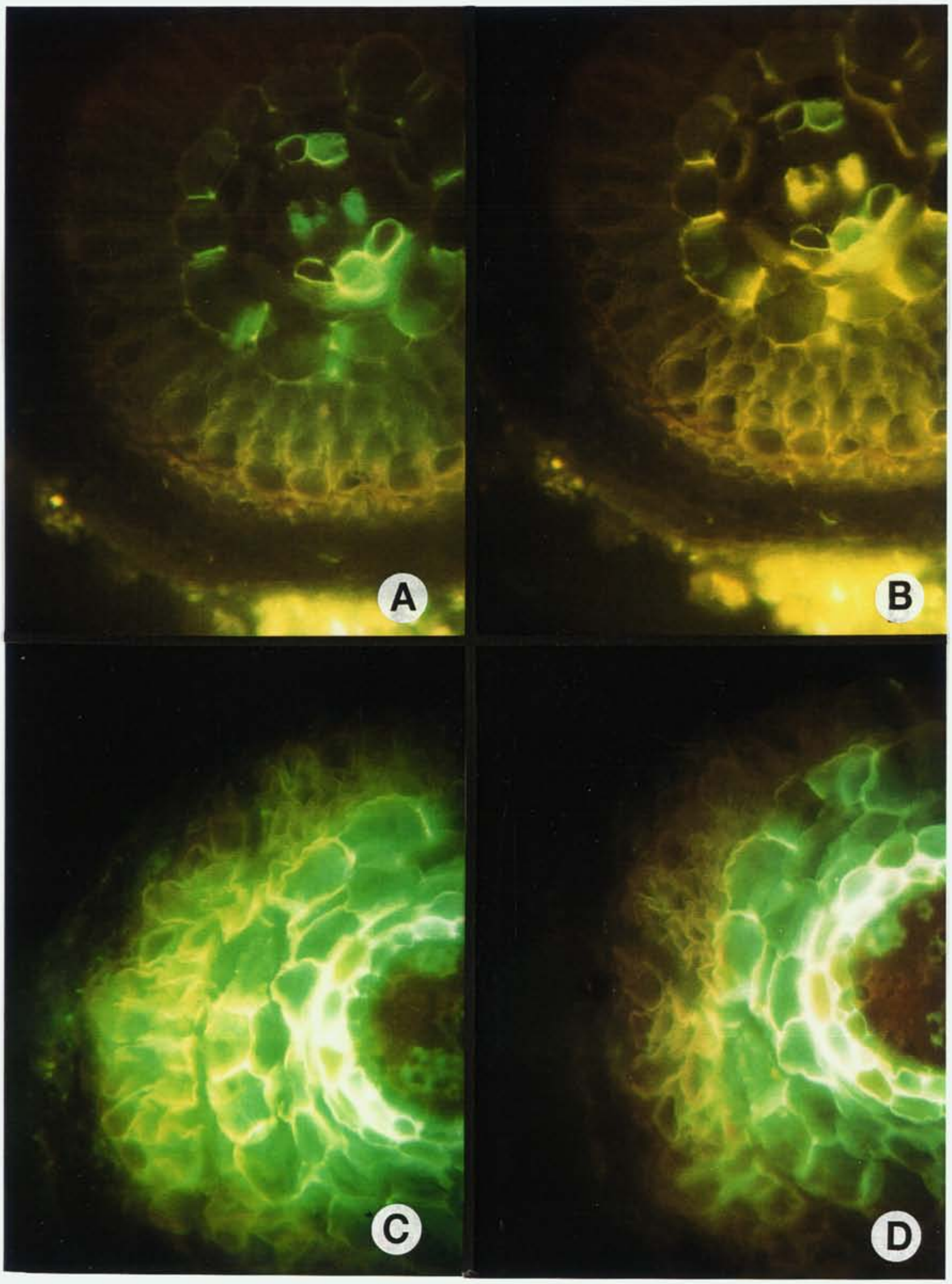

Appendix 12-51: Xerocomus badius

Fruiting body Occurrence: *Xerocomus badius* fruiting bodies were ommon in both the unlimed and limed plots in the fall 2000 but absent in the fall 2001.

Mycorrhizal Occurrence: Absent to Rare. Found only in unlimed soil in spring 1999 at 0-10 cm depth and a few poor examples in fall 1999 in both unlimed and limed soil. (Appendix 8A-B3-66).

Mycorrhizal Morphology: Refer to Agerer (1987-1998) plate 49. The older root used was typical for the external features of *Xerocomus badius* as cited by Agerer. The inner hartig net area was collapsed but the mantle (12 rows thick) exhibited very tight masses of hyphae. No dolipores were seen but double nucleii were evident occasionally as were complete septa.

Fungal Autofluorescence: Blue in UV light and non-fluorescent in the Hartig net area to green in the outer mantle with a green filter. Extremely tiny yellow specks were distributed evenly over the mantle but not incorporated into the cell walls. (Figure 12-51B, 51C)

Root Autofluorescence: Typical in UV light, similar in green light except the phloem fluoresced faint greenish - yellow. (Figure 12-51B, 51C)

Fungal Aluminum: Aluminum was absent even after repeated trials, fresh solutions and different filter combinations. (Figure 12-51A, 51D)

Root Aluminum: Absent. (Figure 12-51A, 51D)

Summary: Neither the mantle nor the root contained aluminum in unlimed soil. There was no comparison to limed probes.

Figure 12-51A: ***Xerocomus badius*** **with Morin > 5 mm from tip.** Mantle and root continue to fluoresce blue even after Morin treatment. No change indicating no aluminum was present. Even when repeated with fresh Morin, no aluminum was found to be present. Probe 1NA from unlimed soil at 0-10 cm depth, spring 1999. Lx. 250x. Photo 5-2, clear filter, 15 second exposure, 20 minutes after treatment.

Figure 12-51B: ***Xerocomus badius*** **autofluorescence > 5 mm from tip.** Mantle and root both autofluoresced blue. Probe 1NA from unlimed soil at 0-10 cm depth, spring 1999. Lx. 250x. Photo 4-36, clear filter, 15 second exposure.

Figure 12-51C: ***Xerocomus badius*** **> 5 mm from tip using Green filter.** Some differentiation of mantle was evident using a green filter for the UV light. The inner mantle was non-fluorescent, outer pale yellow-blue, phloem was pale yellow, remaining cells faint to bright blue. Probe 1NA from unlimed soil 0-10 cm depth. Cx. 250x. Photo 5-4, green filter, 30 second exposure.

Figure 12-51D: ***Xerocomus badius*** **> 5 mm from tip with Morin and Green filter.** Even using a different filter combination, no indication of aluminum could be found. Probe 1NA from unlimed soil at 0-10 cm depth. Cx. 250x. Photo 5-5, green filter, 60 second exposure.

12·51