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Investigations on Mycorrhizae and Fine Roots in an Area used as Forest Pasture

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Summary

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On the Schulterberg, at an altitude of 1640 m a.s.l. (Achenkirch project area), investigations on mycorrhiza and fine roots were carried out at the end of the 1991 grazing season in an area used as pasture. The evaluation of 900 cylinder samples (100 ml), taken from an area of 400 m^2, showed considerable differences between small forest and pasture sites. Where there were trees the dry weight and the density of mycorrhizae and fine roots were higher. The diversity of the mycorrhizae and their vitality were those of a healthy forest in good condition. In areas used for grazing dead mycorrhizae and fine roots were frequently found. It is assumed that this damage, as well as the resulting poorer vitality, is due to the mechanic stress of the soil caused by grazing cattle or sheep. It is evident that the quantitative features which can be established in respect of mycorrhizae do not provide sufficient information to allow an evaluation of the site quality and that qualitative features must be taken into account for that purpose. No pollutant-related deformation of mycorrhizae was observed. From seed experiments, which can be used to assess natural regeneration, the following results have been obtained: The roots of 2-year old seedlings developed poorly on sites used for grazing, moderately around trees, and well, or even very well, on rotting wood. The feature assessed was the length of the roots. The development of the mycorrhizae also proved to be heavily dependent on the substrate and, therefore, can be used as a site indicator.

Introduction

In sub-alpine forests, i.e. in forests characterized by extreme climatic conditions and short vegetation periods, ectomycorrhizae are of special importance. A reduction of the mycorrhiza cover or its impairment through the reduction of the

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fungal components would mean reduced nutrient supply and, consequently, reduced vitality for each and every tree.

The Schulterberg forest is a typical example of the over-mature, thinned-out protection forests of the sub-alpine region of the Northern Limestone Alps.

As regards man-made pollutants, ozone and the relatively high inputs of heavy metals represent potential risks according to the current standard of knowledge (HERMAN & SMIDT 1994, MUTSCH 1995). The area of investigation includes long-standing grazing allotments. Forest pasturing, which is frequently referred to in connection with the urgent need of rehabilitation of sub-alpine protection forests, has therefore been a long-lasting factor of influence.

In the present report the status of mycorrhizae from a forest pasturing area will be described with a view to any conclusions regarding soil stress caused by grazing cattle or sheep. In addition, the formation and development of mycorrhizae will be discussed in connection with pollution input, and the chances to achieve sufficient natural regeneration will be examined by observing the growth habit of seedlings.

Table 1. Vitality classes for fine roots and mycorricae.

I. Good development
Roots: smooth bark, growth of tips unaffected. Mycorricae of the growth habits that are typical of the respective fungi and trees.

II. Visible damage
Some root damage; early aging of mycorricae.

III. Remarkable damage
Root damage; longitudinally compressed root tips; early aging and changes in the growth habit of the mycorricae.

IV. Very remarkable damage
Root damage; visible secondary damage infestation by undesirable fungi, significantly compressed or dead root tips. Early aging of mycorricae; changes in habit, such as compression or fascicular growth.

V. Significant damage
Roots partly dead; visible secondary damage infestation by undesirable fungi; heavily compressed, broken or dead root tips. Mycorricae dead or sparse new mycorricae; changes in habit, such as compression or fascicular growth.

VI. Extreme damage
Roots and mycorrhicae completely dead. Significant damage.

Material and Methods

The location of the sample plots and their structures were described in GÖBL 1995. Samples were collected from small-sized plots which had either been used as pastures or which, for different periods of time, had not been used for grazing. The small plots were characterized, described in respect of their pH values and the rooting of the soil. The dry weights of fine roots and mycorrhizae were determined. The species of the mycorrhizae and the vitality of the fine roots and mycorrhizae were identified and evaluated by the scheme of the vitality classes shown in Table 1 and Fig.1 (page 203).

In 1991 investigations on mycorrhizae and experiments with juvenile plants were started on the Schulterberg. They are meant as a basis of rehabilitation measures and of the evaluation of changes that might occur as a result of interruptions of forest pasturing or other activities.

Results and Discussion

Characterization of the small-sized sites

Table 2 summarizes the pH values, the rooting of the soil, and the dry weights of the fine roots and the number of mycorrhiza species.

Table 2. Characteristic features of the sample area.

Dominant plant species	pH ($CaCl_2$)	Rooting (% of all roots)	Dry weights (g) of the fine roots	Dry weights (g) of mycorrhizae	Number of mycorrhiza species
None (needle litter)	3.31	92	0.66	0.14	21
Vaccinium myrtillus	3.14	98	0.12	0.05	16
Mosses	4.04	100	0.31	0.06	14
Nardus stricta	3.41	94	0.32	0.05	14
Alchemilla alpina. Carlina acaulis. Thymus sp.	5.86	37	0.08	0.02	6
Poa alpina. Plantago alpina	4.86	45	0.15	0.03	12
Deschampsia cesp..Luzula sylvatica	4.02	94	0.64	0.11	17
None (rotted wood)	3.94	98	0.19	0.10	10

pH values: The pH values varied significantly: They were between 3.14 and 4.04 for plots near trees, approximately 3.41 in the Nardetum, and between 4.89 and 5.86 for the syncline and hillock areas rich in herbs. The standard deviation of the mean values from individual plots varied between 1 % and 11 %, which is little and therefore indicates that the conditions of the sub-plots are relatively uniform.

Rooting of the soil: Near trees 94 % to 100 % of all samples were penetrated by roots, which is a very good percentage. For the Nardetum, which is part of the synclines in the pasturing areas, the results were similar (94 %); as opposed to this, less than half of the samples were rooted on syncline sites with *Poa alpina* or on hillock sites with *Alchemilla alpigena*.

Dry weights of fine roots and mycorrhizae: The dry weights of the fine roots and of the mycorrhizae alone did not show any remarkable difference between the two soil layers (depths: 0-5 cm and 5-10 cm); so the results were combined: The standard deviation of the mean values of the individual plots varied between 50 % and 168 % for mycorrhizae and between 51 % and 149 % for the combined total weights, which is extraordinarily high.

The mean values of all individual plots of the small-sized sites indicated that in the areas with trees the cover with mycorrhizae and fine roots was several times denser than it was in areas used for grazing and located outside the canopies.

Number of mycorrhiza species: The small-sized sites of the area of investigation differered significantly in respect of the frequency of certain species, which indicates that soil and vegetation play an important part in that connection (Table 2). The highest diversity and frequency were determined for tree areas. Some species occurred with different frequency in the entire area of investigation; on the small plots with *Vaccinium myrtillus*, mosses, and *Nardus stricta* groups of specific species were found.

For the vegetation period between 1991 and 1993 fruit-bodies from 24 fungal species were identified on the area of investigation (PEINTNER, pers. comm.).

To permit the evaluation of the investigation area, results about the number of mycorrhiza species on various, mainly alpine and sub-alpine forest sites of the Central Alps and the Northern fringe of the Alps have been compiled in Table 3. The data come from sites that are characteristic of the respective area, they were processed according to relatively easily comparable methods.

The high diversity of species (17 to 21) determined on the Schulterberg indicates that on the small-sized sites with trees forests are healthy and in good condition; for a comparison, only 6 mycorrhiza species were identified in the pasturing areas.

Vitality of fine roots and mycorrhizae: In areas covered by trees, where the branches almost touch the ground, vitality corresponds to the average of the classification system and is about standard. In the sub-plot with *Vaccinium myrtillus* more than 25 % of the samples showed good results, which is moderate average. The small tree plots with *Deschampsia cespitosa* and *Luzula sylvatica* and the grazing plots with *Nardus stricta* showed poor and very poor vitality values despite their good rooting values.

Although degrees of damage differed on the individual plots (Table 4), there were similar features. Usually well-developed, sometimes richly branched mycorrhiza systems had died off. Some of them were still young, which was obvious from their light or sparkling tops or from the fact that their tops had not yet solidified. Axes of such systems and, above all, their carrier roots had clearly died off.

Table 3. Number of mycorrhiza species of spruce from different areas of investigation and forest areas.

Experimental site		Altitude a.s.l.	Type(s) of soils	Number of soils	Authors
Schulterbergkuppe/T.	Under canopies	1640 m	Rendsina and brown podsolic soil	17-21	GÖBL (1995)
Schulterbergkuppe/T.	Area used for grazing	1640 m	Rendsina and brown podsolic soil	6-14	GÖBL (1995)
Zillertal/T.	Forest site without use of litter	1060 m	Brown podsolic soil	13-15	GÖBL (1989)
Zillertal/T.	Forest site with use of litter	1520 m	Brown podsolic soil	7-10	GÖBL (1992)
Zillertal/T.	Forest site	1420 m	Brown podsolic soil	14-18	GÖBL (1965)
Gleingraben/Stmk.	Forest site	1270 m	Brown podsolic soil	14-16	GÖBL (1990)
Gaisbergkuppe/Sbg.	Forest site	1240 m	Terra fusca	17-21	GÖBL, unpublished data
Davos/CH.	Forest site	1660 m	Ferric humus podsol	11-15	EGLI (1991)
Lägeren/CH.	Forest site	685 m	Brown soil	13-15	EGLI (1991)

Table 4. Assessment of the vitality classes of fine roots and mycorrhizae in different small communities of a forest pasture (in % of the samples penetrated by roots, n=150 or n= 50*).

Small-sized sites, characterized acc. to dominant plants	Vitality classes I	II	III	IV	V	VI
No plants (needle litter)	-	1,4	22,3	28,1	18,7	29,5
Vaccinium myrtillus *)			13,6	25,0	29,5	31,9
Mosses *)			7,8	14,6	27,5	45,1
Alchemilla alpigena, Thymus sp.			3,6	3,6	14,3	78,5
Deschampsia cesp., Luzula sylvatica			1,4	5,0	10,8	82,7
Nardus stricta				2,2	3,6	94,2
Poa alpina, Plantago alpina					5,0	95,0

For the sub-plots "needle litter" without plant cover and the plot with *Deschampsia cespitosa* and *Luzula sylvatica*, dry weights of 0.66 and 0.64 g per 100 ml of soil were determined. On the plots of pasturing areas the values of 0.32 g determined for the hillock sites of the Nardetum are relatively high compared to the hillock sites with *Poanalpina* and *Plantago alpina* and the syncline sites with *Alchemilla alpigena*, for which very low values were determined (0.01 g and 0.08 g per 100 ml of soil). The low root weights of spruce on the sub-plot *Vaccinium myrtillus* are attributed to their root competition.

For fine roots from forest stands of Vorarlberg PÖDER & PERNFUSS 1994 determined dry weights between 0.72 g and 0.2 g per 100 ml of soil and deviations from the mean value of 4 % to 15 %.

We know from earlier investigations in various Austrian forest stands that the distribution of mycorrhizae and fine roots can be very irregular despite external homogeneity of the sample plots, high density/number of sample plots, and most careful handling of the samples (GÖBL 1990). This may be due to: the course of the roots; the specific, sometimes very dense branching of certain mycorrhiza species; root competition between herbs and grasses (SOBOTIK & POPPELBAUM 1995); soft rotting of certain parts of the roots, differences in the soil over smallest-sized areas; or damage caused by external influences.

The irregularities in the distribution of mycorrhizae and fine roots on the Schulterberg sample plot might also be due to the mosaic of different small sites, the distribution of trees by groups, and the high age of the trees; there are no ways of comparison in that respect.

The above results indicate stress. However, there is no proof of the roots having been attacked by parasite fungi or other harmful organisms; seeing the precipitation values, also damage caused by drought does not provide an explanation (PLATTNER & PAUSCH, pers. comm.). The examination of other site-related features, such as, for instance soil-chemical factors, showed only connections with the frequency and distribution of species.

A description of the damage situation of the entire area using the mean values of the vitality classes of the individual plots (Fig. 1, Table 1) shows clearly that the areas used for grazing and located outside the almost inaccessible canopies (i.e. the small sites rich in grass and herbs) are most seriously affected. Mechanical injury of fine roots and the dying off of mycorrhizae as a result of trampling stress caused by grazing animals are therefore obvious explanations of the described damage.

In spring, prior to the sprouting of grass and herbs, the peeling off of the vegetation layer indicate that those small sites are stressed. According to ZAUPER 1990 the turf is much more spoiled, or peeled off (up to 10 %), on adjacent mountain pastures that are intensively used for grazing.

Assessment of damage: The described changes that occur in the area of the fine roots after the end of the pasturing season correspond to a reduction of the density of fine roots and mycorrhizae and, consequently, to a reduction of the absorption organs. As the damage is rather heavy, reduced water supply, reduced nutrient uptake or insufficient supply with certain nutrients can be considered immediate consequences for the trees.

It seems justified to assume that such damage will re-occur, always depending on how intensely the areas are used for grazing. Considering the long-term use as pasture and the high age of the trees, one can say that the damage has been the cause of the impaired health of the trees.

Correlations between the development of mycorrhizae and pollution input

Pearl-string constrictions on mycorrhizae or the thinning of their tops indicate minor (seasonal) changes in the environmental conditions in respect of water/nutrient supply or pollution input. These modifications, too, were found only on a small number of samples; for forest pasture sites, they are insignificant. The frequent occurrence of that growth habit on pure pastures indicates that the conditions for the root development of forest plants are rather poor.

Abnormal developments of mycorrhizae, such as changes in form, structure, or frequency, may indicate the instability of forest ecosystems.

Changes of the mycorrhiza-forming fungal partner on individual mycorrhizae, occurring mostly in the top regions and easily recognizable by differing colours and structures of the fungal coats, indicate the impairment of the competitive behaviour of the fungal partners.

On a 40-year old pine stand, MARKS & FOSTER 1973 identified about 4 % of such mycorrhizae. Forest damage areas show up to 62.8 % of abnormally developed mycorrhizae on the roots of planted young spruce after one vegetation period (GÖBL, in preparation). In the Schulterberg investigation area, that growth habit was found in only 7 out of 900 individual samples. Although there is little chance of comparison, this does not indicate pollution input.

Seed tests

The spruce seeds began to germinate almost simultaneously three weeks after seeding. The further development of the seedlings, in particular that of their roots, depended considerably on the substrate of the seed places. The characteristic growth habits can be seen from the example of the 2-year old seedlings of Fig. 2.

On the pastures, the roots of the seedlings were very tender and only little branched; in the area of the trees on forest soils they were short and compact. The plants on rotted wood showed a completely different growing behaviour. Mean root lengths of 26.5 cm were reached on those sites after only one vegetation period, while on forest sites the roots of the plants averaged only 3.5 cm after the same period of time.

These results correspond very well with the seed tests of EICHRODT 1969, which showed long main roots on mouldy wood substrate, but shorter ones on brown soil.

The decaying of the wood is caused by two major species of wood-decomposing fungi (JAHN 1979). Those causing brown rot decompose mainly cellulose, which leads to blockish decay or cubic cracking. The wood remains relatively hard; the roots of the spruce seedlings follow almost exclusively the existing crevices, are bent in right-angles, and, depending on the degree of rottenness of the wood, can reach considerable lengths compared to those on soil. Fungi causing white rot, on the other hand, disintegrate lignin and therefore cause fibrous decay. As the wood reaches an advanced stage of rottenness, the roots find almost no resistance any more and can grow across the substrate in various directions.

Occurrence and distribution of wood-decomposing fungal species on the Schulterberg were studied by PEINTNER & MOSER 1995.

Great differences were observed also in the development of mycorrhizae on seedlings (Fig. 3). On pure pastures, the little and irregularly affected short roots showed pearl-string constrictions, which indicates unfavourable conditions for the development of roots.

The poor mycorrhization of those seedlings is a first indicator of mycorrhizae playing an important part in rehabilitation afforestations of long-term deforested sites on calcareous parent rock.

On the forest sites of the Schulterberg a small number of mycorrhizae had differentiated after only one (the first) vegetation period; after the second vegetation period there were already several different species, always depending on the mycorrhization potential of the respective seed place.

After a certain degree of decay has been reached also mycorrhizal fungi can colonize the mouldy wood and produce mycorrhizae on the roots of seedlings or on external roots of mature trees (GÖBL 1968). The humidity and the well-balanced temperature of the substrate allow permanent growth and a rather good differentiation of the mycorrhizae (HARVEY & al. 1978).

The humidity and the balanced temperature of the substrate also allow permanent root growth and mycorrhiza differentiation. On the Schulterberg, roots of seedlings frequently showed mycorrhizae from fibrously decayed, mouldy wood which corresponded to the vitality classes I or II.

In the Schulterberg forest natural regeneration is restricted to the decayed stems and stumps. Their higher location does not only provide the better substrate for the development of roots and mycorrhizae, it also protects the plants from trampling and browsing damage caused by grazing animals and deer.

According to EICHRODT 1969 mouldy wood in general provides ecologically valuable conditions for the development of spruce in sub-alpine forests. For instance, the somehow elevated temperature of mouldy wood shortens the time of snow. For natural regeneration on those special sites of the Schulterberg that explains the low number of attacks by the harmful fungus *Herpotrichia nigra* (snow blight). That forest sites are covered by snow for a long time has favoured the propagation of that fungus, which caused high losses of planted spruce.

The Schulterberg forest offers numerous examples which demonstrate that the described method of regeneration is used not only today, but has also been characteristic in the past. The growth habits of the roots have remained adjusted to elevated sites; they can still be seen on mature trees. The stilt-rootish form of roots endangers the stability of the trees, or of the entire stand; a fact which is probably closely connected with the proneness of old trees to windthrow.

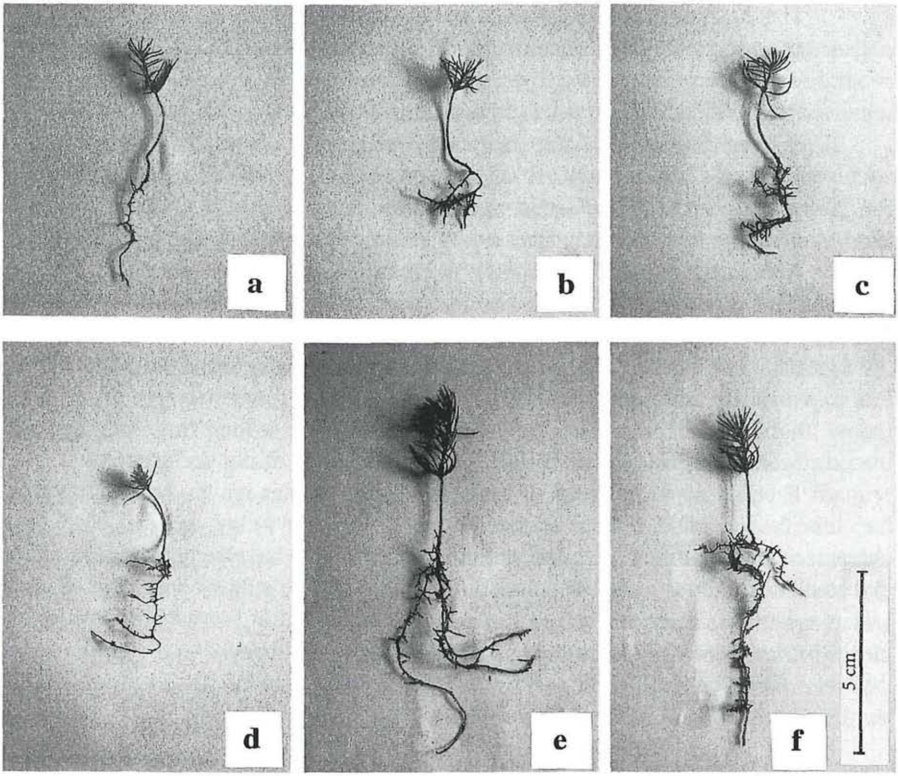


Fig. 2. Two year old spruce seedlings on pasture (a), forest ground (b, c) and on rotting wood (d, e, f).

Fig. 1. Classes of vitality of fine roots and mycorrhizae.

Fig. 3. Mycorrhizae of two year old seedlings on pasture (a), forest ground (b, c) and on rotting wood (d: cubic fracture, e,f: fibrous fracture).

Figure 1: Classes of vitality of fine roots and mycorrhizae (1-5)

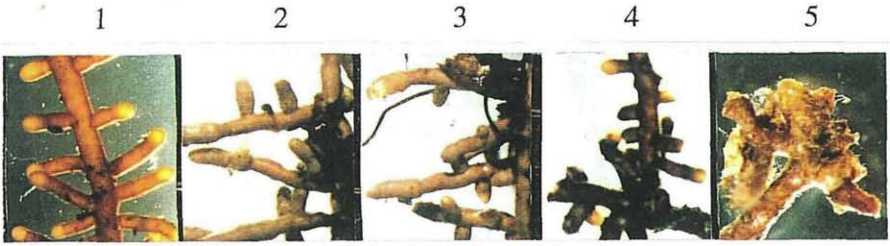
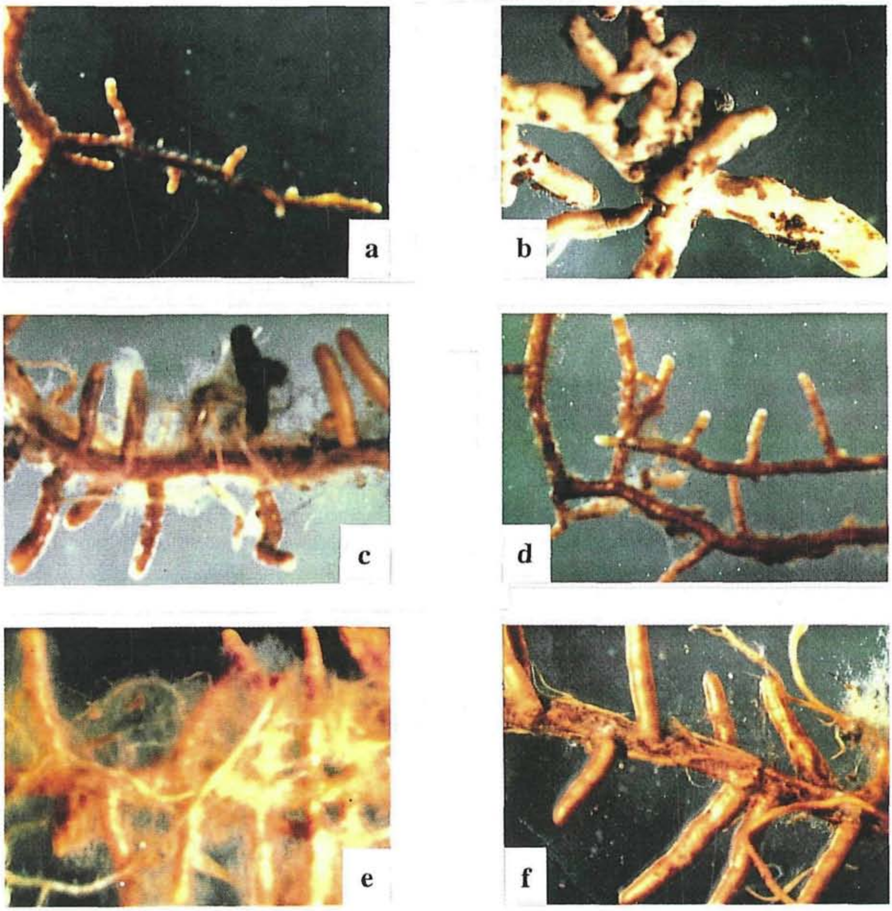


Figure 3:



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