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Mycorrhizal plants of traditionally managed boreal grasslands in Norway

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Abstract This paper reports on the mycorrhizal status of 82 plant species growing in traditionally managed grasslands in three different locations in the boreal and boreonemoral vegetation zone in the eastern part of Norway. Seventy-four species were found to have arbuscular mycorrhiza (AM). To our knowledge, we report AM for the first time in *Achillea ptarmica*, *Ajuga pyramidalis*, *Alchemilla glaucescens*, *Carex brunnescens*, *Carex pallescens*, *Crepis praemorsa*, *Hieracium lactucella*, *Rumex longifolius*, *Scorzonera humilis*, *Trifolium aureum* and *Trifolium spadiceum*. The rare and threatened species *Arnica montana*, *S. humilis*, *C. praemorsa*, *Gentianella campestris*, *Parnassia palustris*, *T. aureum* and *T. spadiceum*, all confined to grasslands, were found to possess AM fungi.

Keywords Arbuscular mycorrhiza · Semi-natural grasslands · Conservation · Rare plant species · Restoration

Introduction

Since the middle of the last century, land use changes and intensification of practices have led to the loss of plant habitats and species all over Europe (Londo 1990), including Norway (Olsson et al. 2000). About 50% of the rare and threatened plant species in Norway belong to the cultural landscape, which comprises a mosaic of agricultural fields, semi-natural grasslands (pastures and meadows), and edge zones of forests, all of which are influenced by human activities and domestic animals. Many of the species grow in remnants of traditionally managed meadows and pastures in the boreal zone. The conservation value of these grasslands is high because of the species composition, the high diversity and the cultural history they represent (Ingeløg et al. 1993) but, being situated in marginal areas, rural exodus and forest plantations have caused considerable loss and fragmentation of these habitats. Conservation options here comprise both preserving grasslands by appropriate management, and restoration of suitable sites. Better understanding of biotic interactions is regarded as vital in both cases. A number of studies have highlighted and reported the importance of mycorrhiza in grassland restoration, e.g. North-American prairies (Dhillion and Friese 1994; Smith et al. 1998), Mediterranean garrigue (Roldan-Fajardo 1994) and boreal grasslands (Dhillion 2000; Dhillion and Antonsen 2001).

In this study we focus on arbuscular mycorrhiza (AM) in species-rich grasslands in Norway with the long term aim of including mycorrhizal studies in boreal grassland restoration and conservation. AM is thought to have a structuring effect on plant species composition in different grassland ecosystems (Francis and Read 1994; Zobel et al.1997). For example, Van der Heijden et al. (1998) found that mycorrhizal fungal diversity can determine plant biodiversity, ecosystem variability and productivity, and concluded that it is necessary to protect the diversity of arbuscular fungi and to consider these fungi in future management practices in order to maintain diverse ecosystems. In Norway, the grasslands have many precious species which are used and maintained by farmers through traditional grazing and haying practices. The issue of maintaining a certain productivity is thus essential for land managers, farmers and conservationists alike, who have to maintain a balance between use and maintenance of diversity (Dhillion and Antonsen 2001).

Although mycorrhizal plant species are reported to occur in high numbers in different grassland types, only a few publications exist dealing with the AM status of plants in semi-natural grasslands in the boreonemoral or boreal vegetation zone (Dhillion 1993, 1994; Väre et al.

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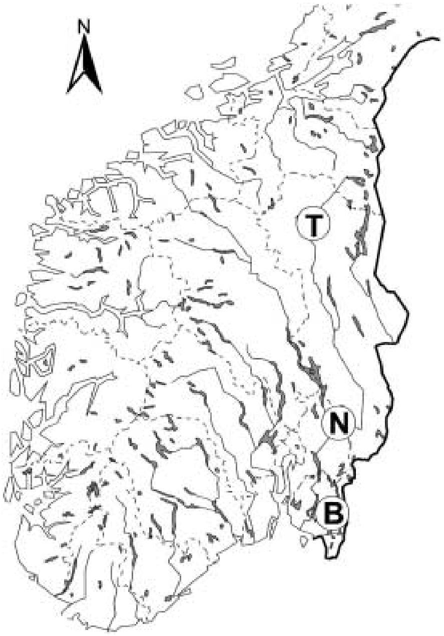

Fig. 1 Map of southern Norway showing the three locations where plant species were sampled. *B* Bøensætre, Aremark municipality in the county of Østfold. *N* Nes municipality in the county of Akershus. *T* Tylldalen, Tynset municipality in the county of Hedmark

1997; Eriksson 1999). Here we present the AM status of 82 different plant species growing in traditionally managed, non-fertilised grassland habitats in Norway. Plant species studied include common, as well as nationally or regionally rare and threatened, species.

Study sites

Study sites included traditionally managed grasslands from three counties (Østfold, Akershus and Hedmark), situated in the eastern part of Norway (Fig. 1).

The first site, Bøensætre (B), is situated in the municipality of Aremark in Østfold. The grasslands are located in the weak oceanic section of the boreo-nemoral vegetation zone (sensu Moen 1999). It is a cotter's farm landscape with small farms surrounded by forest. The area is on the list of chosen smaller special landscapes in the Norwegian national survey of valuable cultural landscapes (Båtvik 1997).

The second site, Nes (N), is situated in the municipality of Nes in Akershus. Like Bøensætre, it is a cotter's farm landscape located in a large, continuous forest between Sør-Odal, Eidskog and Aurskog, characterised as belonging to the weak continental part of the south boreal vegetation zone (sensu Moen 1999). During the eighteenth and nineteenth centuries this area was a summer farming area for the farms on the eastern side of the Glomma river. Many of the smaller farms are now abandoned or have been converted to summer cottages. The "summer farm and cotter's farm landscape" is more fragmented than previously, but still distributed all over the forest.

The third study site, Tylldalen (T), is situated in the municipality of Tynset in Hedmark. The grasslands are located in the continental section of the middle boreal vegetation zone (sensu Moen 1999). The sites studied are parts of the spring and summer farming areas, still managed with grazing and haying. These grasslands form the most important part of the off-farm resources that the local farmers were dependent upon before the 1960s (S.S. Dhillion and A. Fløgstad, unpublished data). The area as a whole remains one of the few areas in Norway where traditional "transhuman" practices remain. Of the three sites, this one is highly mountainous ranging from 550 to 950 m in elevation for grassland locations.

Materials and methods

We collected between 2 and 11 individuals of each plant species at anthesis during June, July and August in 1999. Twelve species were collected from all three locations. The rest were collected from either one or two locations.

Plants in the flowering stage were excavated, and entire root systems were washed and fixed in 45% ethanol. They were cleared with 5% KOH and stained with trypan blue according to Phillips and Hayman (1970) modified by Koske and Gemma (1989). Heavy pigmentation was reduced using alkaline H_2O_2. Stained root segments were observed for internal hyphae, arbuscules and vesicles using a compound microscope. The internal hyphae without septa and with attached arbuscles or vesicles were considered to be AM.

Our observations were checked against the list of references in Harley and Harley (1987), and the number of publications reporting the mycorrhizal status for each plant species was added to Table 1. Some Norwegian species do not occur in Great Britain, but on the whole Harley and Harley (1987) included 87% of the investigated species. Nomenclature follows Lid and Lid (1994).

Results and discussion

The majority of the investigated species (74/82) had internal hyphae and either arbuscles, vesicles and/or swollen hyphae (Table 1). Our investigations did not reveal noticeable differences in infection between the three locations. Among the plant species examined, *Juncus filiformis*, *Rhinanthus minor*, *Rumex longifolius* and *Silene dioica* had AM structures only in a very few specimens (Table 1). Internal hyphae were observed in some specimens of *Euphrasia stricta*, *E. nemorosa*, *Myosotis decumbens* and *Rumex acetosella*, but no visible arbuscules or vesicles were present. No internal hyphae, nor arbuscules or vesicles were detected in *Galium album*, *Melampyrum pratense*, *M. sylvaticum* or *Urtica dioica*.

To our knowledge, we report AM for the first time in *Achillea ptarmica*, *Ajuga pyramidalis*, *Alchemilla glaucescens*, *Carex brunnescens*, *Carex pallescens*, *Crepis praemorsa*, *Hieracium lactucella*, *R. longifolius*, *Scorzonera humilis*, *Trifolium aureum* and *T. spadiceum*.

The semi-parasite *E. stricta* was found to be nonmycorrhizal, in agreement with the references concern-

Table 1 The arbuscular mycorrhiza (AM) status of 82 vascular plants in semi-natural grasslands from three localities in SE Norway (*B* Bøensætre in Aremark municipality, *N* Nes municipality, *T* Tylldalen in Tynset municipality). For X/Y, X and Y indicate the number of AM and non-AM individuals sampled, respectively. In the last column, the number of references reporting presence (+) and absence (–) of AM in Harley and Harley (1987) are listed, and ECM indicates number of references reporting ectomycorrhizal infections. Nomenclature follows Lid and Lid (1994)

Plant species	Internal hyphae			Arbuscules			Vesicles			References of AM status in Harley and Harley (1987)
	B	N	T	B	N	T	B	N	T	
Achillea millefolium L	8/9	2/3	9/10	5/9	2/3	4/10	8/9	2/3	3/10	+12 –0
Achillea ptarmica L	3/3	4/4	3/3	3/3	4/4	3/3	3/3	3/4	2/3	+0 –1
Agrostis capillaris L	6/6	4/4	10/10	3/6	4/4	10/10	3/6	4/4	3/10	+11 –1
Ajuga pyramidalis L	2/2	–[a]	–	2/2	–	–	2/2	–	–	Not mentioned
Alchemilla alpina L	n.e.[b]	n.e.	4/6	n.e.	n.e.	4/6	n.e.	n.e.	3/6	+1 –0
Alchemilla glaucescens Wallr	–	2/2	n.e.	–	2/2	n.e.	–	2/2	n.e.	Not mentioned
Antennaria dioica (L.) Gaertner	2/4	4/4	–	2/4	2/4	–	1/4	3/4	–	+4 –0
Anthoxanthum odoratum L	6/6	–	8/8	6/6	–	8/8	6/6	–	6/8	+10 –3
Arnica montana L	2/3	4/4	n.e.	0/3	3/4	n.e.	2/3	3/4	n.e.	Not mentioned
Bistorta vivipara (L.) S.F.Gray	3/4	–	5/5	0/4	–	3/5	4/4	–	0/5	+1 –0 ECM 9
Botrychium lunaria (L.) Swartz	3/3	3/3	5/5	3/3	3/3	5/5	3/3	3/3	2/5	+15 –0 (sporophyte)
Campanula persicifolia L	5/5	n.e.	n.e.	2/5	n.e.	n.e.	4/5	n.e.	n.e.	+0 –2
Campanula rotundifolia L	6/6	1/1	–	2/6	0/1	–	3/6	0/1	–	+5 –1
Carex brunnescens (Pers.) Poiret	n.e.	n.e.	3/5	n.e.	n.e.	2/5	n.e.	n.e.	0/5	Not mentioned
Carex nigra (L.) Reichard	–	3/3	3/5	–	3/3	0/5	–	3/3	0/5	+1 –1
Carex pallescens L	2/5	0/1	–	1/5	0/1	–	2/5	0/1	–	+0 –2
Carex panicea L	1/3	2/3	n.e.	1/3	2/3	n.e.	1/3	1/3	n.e.	+2 –4
Carum carvi L	3/3	–	3/4	1/3	–	2/4	2/3	–	2/4	+1 –0
Centaurea jacea L	5/5	3/3	n.e.	3/5	0/3	n.e.	5/5	3/3	n.e.	+4 –0
Cerastium fontanum Baumg	4/4	–	4/4	1/4	–	3/4	3/4	–	0/4	+1 –3 (ssp. glabrescens)
Crepis praemorsa (L.) Tausch	6/6	3/3	n.e.	6/6	3/3	n.e.	5/6	2/3	n.e.	Not mentioned
Danthonia decumbens (L.) DC	3/3	3/3	n.e.	0/3	3/3	n.e.	3/3	3/3	n.e.	+3 –0
Deschampsia cespitosa (L.) Beauv	–	–	10/10	–	–	8/10	–	–	4/10	+9 –0
Deschampsia flexuosa (L.) Trin	–	–	10/10	–	–	5/10	–	–	5/10	+9 –0
Euphrasia stricta D. Wolff ex J.F.Lehm	–	0/7	2/6	–	0/7	0/6	–	0/7	0/6	+0 –5 (for the genus)
Euphrasia nemorosa (Pers.) Wallr	n.e.	1/2	n.e.	n.e.	0/2	n.e.	n.e.	0/2	n.e.	+0 –5 (for the genus)
Festuca ovina L	3/3	4/4	–	2/3	3/4	–	3/3	4/4	–	+20 –1
Festuca pratensis Hudson	5/5	3/3	5/5	3/5	1/3	3/5	4/5	3/3	3/5	+3 –1
Filaginella uliginosa (L.) Opiz	1/1	3/9	n.e.	0/1	1/9	n.e.	1/1	2/9	n.e.	+2 –0
Galium album Miller	–	0/3	0/6	–	0/3	0/6	–	0/3	0/6	+2 –0
Gentianella campestris (L.) Börner	3/3	3/3	–	1/3	0/3	–	2/3	3/3	–	+1 –0
Geranium sylvaticum L	–	–	6/6	–	–	6/6	–	–	5/6	+6 –0
Geum rivale L	2/2	2/2	–	2/2	2/2	–	2/2	2/2	–	+7 –1
Hieracium lactucella Wallr	–	4/4	n.e.	–	4/4	n.e.	–	4/4	n.e.	Not mentioned
Hieracium umbellatum L	3/3	1/2	–	1/3	0/2	–	3/3	1/2	–	+1 –0
Holcus mollis L	3/3	n.e.	n.e.	0/3	n.e.	n.e.	2/3	n.e.	n.e.	+3 –0
Hypericum maculatum Crantz	3/3	–	–	0/3	–	–	1/3	–	–	+2 –0
Juncus filiformis L	–	–	3/5	–	–	1/5	-	–	0/5	+0 –1
Knautia arvensis (L.) Coulter	3/3	–	5/5	3/3	–	4/5	3/3	–	2/5	+4 –0
Lathyrus pratensis L	–	–	4/6	–	–	3/6	–	–	1/6	+4 –1
Leontodon autumnalis L	–	4/4	5/5	–	4/4	5/5	–	4/4	2/5	+4 –0
Leucanthemum vulgare Lam	3/3	3/3	–	1/3	3/3	–	3/3	3/3	–	+7 –0
Lotus corniculatus L	6/7	–	–	1/7	–	–	7/7	–	–	+13 –2
Melampyrum pratense L	0/6	0/9	–	0/6	0/9	–	0/6	0/9	–	+1 –7
Melampyrum sylvaticum L	–	0/4	–	–	0/4	–	–	0/4	–	+0 –5
Myosotis decumbens Host	n.e.	n.e.	5/5	n.e.	n.e.	0/5	n.e.	n.e.	0/5	Not mentioned
Nardus stricta L	n.e.	6/7	–	n.e.	6/7	–	n.e.	5/7	–	+14 –0
Omalotheca norvegica (L.) Schultz	n.e.	n.e.	4/6	n.e.	n.e.	3/6	n.e.	n.e.	2/6	+4 –0
Parnassia palustris L	6/6	2/2	n.e.	4/6	1/2	n.e.	4/6	0/2	n.e.	+5 –3
Phleum alpinum L	n.e.	n.e.	3/6	n.e.	n.e.	3/6	n.e.	n.e.	0/6	+2 –0
Phleum pratense L	–	–	6/6	–	–	6/6	–	–	2/6	+5 –0
Pimpinella saxifraga L	6/6	1/1	n.e.	2/6	0/1	n.e.	6/6	1/1	n.e.	+5 –2
Plantago media L	n.e.	3/3	n.e.	n.e.	2/3	n.e.	n.e.	3/3	n.e.	+3 –0
Plantago lanceolata L	7/7	n.e.	n.e.	7/7	n.e.	n.e.	7/7	n.e.	n.e.	+17 –0
Poa pratensis L	–	2/3	5/5	–	0/3	3/5	–	2/3	2/5	+7 –5

Table 1 Continued

Plant species	Internal hyphae			Arbuscules			Vesicles			References of AM status in Harley and Harley (1987)
	B	N	T	B	N	T	B	N	T	
Polygala vulgaris L	6/6	4/6	n.e.	2/6	2/6	n.e.	3/6	1/6	n.e.	+2 –0 ECM 1
Potentilla crantzii (Crantz) G.Beck ex Fritsch	n.e.	n.e.	5/6	n.e.	n.e.	3/6	n.e.	n.e.	0/6	+1 –0
Potentilla erecta (L.) Räuschel	4/4	5/5	–	3/4	2/5	–	4/4	5/5	–	+7 –3
Prunella vulgaris L	11/11	–	6/6	9/11	–	5/6	11/11	–	2/6	+9 –1
Ranunculus acris L	9/9	1/1	10/10	6/9	1/1	8/10	9/9	1/1	4/10	+10 –0
Rhinanthus minor L	0/3	3/6	2/5	0/3	0/6	1/5	0/3	1/6	0/5	+0 –2 (for the genus)
Rumex acetosa L	2/3	1/2	5/10	0/3	0/2	2/10	2/3	1/2	0/10	+1 –3
Rumex acetosella L	–	–	3/5	–	–	0/5	–	–	0/5	+0 –2
Rumex longifolius DC	–	–	6/10	–	–	2/10	–	–	0/10	Not mentioned
Saxifraga granulata L	–	2/3	n.e.	–	1/3	n.e.	–	1/3	n.e.	+1 –1
Scorzonera humilis L	6/7	n.e.	n.e.	3/7	n.e.	n.e.	6/7	n.e.	n.e.	Not mentioned
Silene dioica (L.) Clairv	–	1/4	0/5	–	1/4	0/5	–	1/4	0/5	+0 –2
Solidago virgaurea L	–	7/7	–	–	2/7	–	–	6/7	–	+6 –0
Stellaria graminea L	3/5	0/3	3/5	0/5	0/3	2/5	2/5	0/3	0/5	+0 –2
Succisa pratensis Moench	2/2	4/4	n.e.	2/2	3/4	n.e.	2/2	4/4	n.e.	+2 –0
Trifolium aureum Pollich	5/5	n.e.	n.e.	4/5	n.e.	n.e.	5/5	n.e.	n.e.	Not mentioned
Trifolium pratense L	–	2/2	8/8	–	1/2	6/8	–	2/2	2/8	+19 –1
Trifolium repens L	3/3	2/2	8/10	3/3	1/2	7/10	3/3	2/2	5/10	+19 –0
Trifolium spadiceum L	n.e.	3/3	n.e.	n.e.	2/3	n.e.	n.e.	3/3	n.e.	Not mentioned
Trollius europaeus L	n.e.	n.e.	4/5	n.e.	n.e.	3/5	n.e.	n.e.	1/5	+4 –0
Urtica dioica L	–	–	0/5	–	–	0/5	–	–	0/5	+3 –12
Veronica chamaedrys L	5/5	3/4	5/5	3/5	1/4	4/5	4/5	0/4	2/5	+7 –5
Veronica officinalis L	2/2	6/6	5/6	1/2	4/6	5/6	2/2	6/6	5/6	+3 –3
Veronica serpyllifolia L	2/4	–	5/5	2/4	–	5/5	2/4	–	2/5	+1 –0
Vicia cracca L	–	–	9/10	–	–	5/10	–	–	2/10	+4 –0
Vicia sepium L	3/6	–	5/6	1/6	–	2/6	3/6	–	0/6	+3 –0
Viola tricolor L	–	–	4/6	–	–	2/6	–	–	0/6	+3 –1

[a] Not sampled
[b] Not existing in the locality

ing the genus in Harley and Harley (1987). *R. minor*, also a semi-parasite, was found to lack AM structures in most of the investigated specimens. This corresponds with the findings of Davies and Graves (1998) who found that *R. minor* was non-mycorrhizal itself, but had an indirect relationship to AM by having increased growth and reproductive output when the host was mycorrhizal. In addition to *Rhinanthus minor*, *Rumex longifolius* and *S. dioica* were very weakly infected (<1%), suggesting a weak, or lack of, symbiotic relationship.

Harley and Harley (1987), referring to Heinricher (1900), reported that *Polygala vulgaris* had ectomycorrhiza. This must be a misinterpretation, since Heinricher (1900) reported that the specimens he investigated were without mycorrhizal structures. We did not observe ectomycorrhiza in *P. vulgaris*, but we found relatively thick internal hyphae and both arbuscules and vesicles, indicating an AM relationship.

Bistorta vivipara has previously been reported to be ectomycorrhizal (Treu et al. 1996; Väre et al. 1997; Massicotte et al. 1998). In specimens from Aremark, we found unramified, club-like mycorrhiza (Fig. 2), like the ones described by Treu et al. (1996) and characterised as ectomycorrhizal structures. These specimens had dual infections: both ectomycorrhizal and AM structures. This phenomenon has been reported for this species growing in the Alps (Blaschke 1991) and for *Kobresia myosuroides* (Vill.) Fiori from high arctic conditions in Canada (Kohn and Stasovski 1990). From the boreal zone, Dhillion (1994) reported dual infection in two woody species, *Salix glauca* L. and *Salix myrsinifolia* Salisb.

Cyperaceae are widely thought to be non-mycorrhizal (Smith and Read 1997). Our results show that this may not be the case. The four investigated species of *Carex* were all found to have AM structures, in at least one of the locations. A possible explanation might be that our locations were relatively dry compared to where many *Carex* species usually grow. The general description of the genus being non-mycorrhizal may be concluded from investigations on species growing in moist locations. Harley and Harley (1987) report the British *Carex* species as having AM infection. Many of these *Carex* species are found in dry habitats, in contrast to the non-mycorrhizal species from moist places. Another possibility is that the *Carex* species we investigated might be facultative mycotrophs dependent on habitat moisture levels, similar to observations in representatives of the genus *Equisetum* (Dhillion 1993). Further investigations are needed to verify if any of these possibilities are plausible.

The representatives of the Polygonaceae were weakly infected, except for *B. vivipara*, which seems to be a spe-

Fig. 2 Ectomycorrhizal short root of *Bistorta vivipara* which has dual infection. Photo taken with a Leica DC 100 digital camera. *Bar* 100 µm

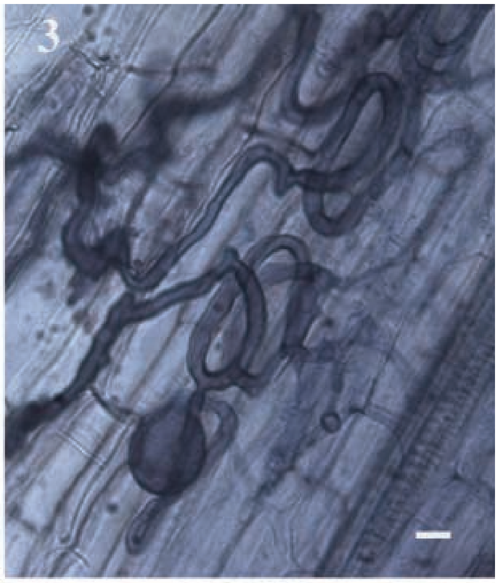

Fig. 3 Internal hyphae and vesicle in the root of *Campanula persicifolia*. Photo taken with a Leica DC 100 digital camera. *Bar* 100 µm

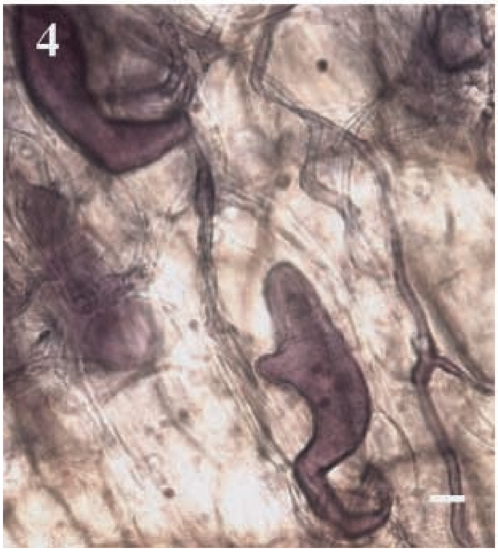

Fig. 4 Internal hyphae and lobed vesicles in the root of the sporophyte of *Botrychium lunaria*. Photo taken with a Leica DC 100 digital camera. *Bar* 10 µm

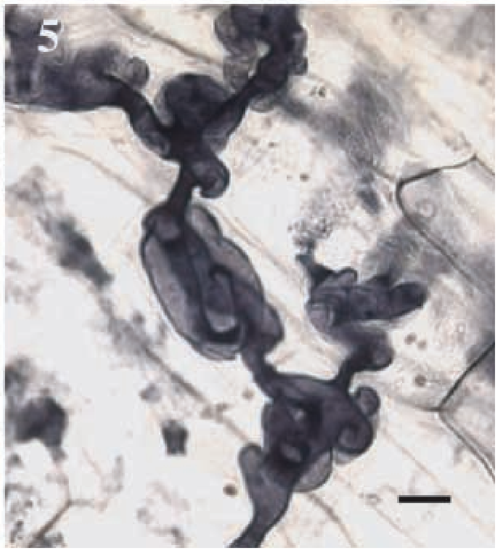

Fig. 5 Swollen internal hyphae from the root of the vulnerable species *Gentianella campestris*. Photo taken with a Leica DC 100 digital camera. *Bar* 10 µm

cial case with dual infection. The general lack of AM structures is in agreement with Polygonaceae being mainly non-mycorrhizal (Smith and Read 1997).

Representatives of the Poaceae play an ecologically important role in grasslands, where they often dominate. We observed AM in all 11 species investigated, in agreement with Read et al. (1976) who found heavy infection in many Poaceae species in semi-natural grasslands in Great Britain. Among mechanisms contributing to explain the key position of grasses is their role in the formation of hyphal bridges connecting root systems of different plant species in the soil (Read et al. 1985), and their potential ability of outcompeting ruderal species facilitating the development of early succession (Smith et al. 1998). Our records are in accordance with earlier reports on AM status in grasses, and this emphasises the importance of considering the role of grasses in re-vegetation and conservation.

Internal hyphae, arbuscules and vesicles were observed in *Achillea ptarmica*, *Campanula persicifolia* (Fig. 3) and *Anthriscus sylvestris*, contrary to what was reported in Harley and Harley (1987). The observations of AM in *A. sylvestris* are in agreement with Kühn et al. (1991), who found AM in material from a fallow agricultural site in Germany, and with Eriksson (1999) who reported AM in the species from semi-natural grasslands in Sweden.

The sporophyte of *Botrychium lunaria* occurs irregularly in grasslands. Schmid and Oberwinkler (1994) found that the small achlorophyllous gametophyte of the species was mycorrhizal and they found lobed vesicles. They claimed that the fungi from the symbiotic gametophyte did not infect the sporophyte. We found the sporophytes heavily infected by AM fungi, and we observed lobed vesicles (Fig. 4) in specimens from all three locations.

Some of the plant species investigated are considered to be in a group that disappear early after cessation of traditional grassland management (Ekstam and Forshed 1992). Among them are *Arnica montana*, *Scorzonera* *humilis* and *Crepis praemorsa*, which also are listed on the Norwegian Red List 1998 (Direktoratet for Naturforvaltning 1999). We found AM structures in *A. montana*, in agreement with investigations of the species in The Netherlands (Heijne et al. 1992), and we report for the first time to our knowledge, AM structures in both *C. praemorsa* and *S. humilis*. *Gentianella campestris* is another vulnerable species, redlisted in Sweden (Ingeløg et al. 1993) and regionally threatened in lowland parts of Norway (Eriksen 2000), where agricultural practices have changed dramatically. Stahl (1900) observed mycorrhizal structures in *G. campestris*. In agreement with this, we found heavy infections with a lot of swollen hyphae (Fig. 5), similar to the structures described by Gay et al. (1982) in the closely related *G. amarella* (L.) Börner. The hyphal loops were coiled up tightly in some specimens, as Jacquelinet-Jeanmougin and Gianinazzi-Pearson (1983) documented for *Gentiana lutea* L., or more loosely as in Fig. 5. *Parnassia palustris* is also threatened regionally, and this species has previously been reported to be either mycorrhizal or non-mycorrhizal (Harley and Harley 1987). This is in agreement with our observations.

Conclusion

The finding of AM structures in 74 of 82 plant species, of which 11 are reported for the first time, clearly indicates that AM must be seriously considered in conservation and restoration programmes concerning semi-natural grasslands in the boreal zone. Today in Norway, no organized research on these issues is supported by leading funding institutions. Virtually all of the grasslands in Norway have been managed or influenced by human activities in the past, and still have to be managed to maintain or develop their inherent value. In many cases this means producing management plans to assess and implement the best management options (Dhillion and Antonsen 2001). Both in conserving species composition, and in introduction and reintroduction of rare and vulnerable species, knowledge about plant interactions above and below ground is a necessity. Registration of AM status for each species can be considered as a first step. It must be followed up by studying fungus-host relationships and dependency, seasonal variations in infection levels and possible specific plant life-stages where AM is crucial. Of particular importance is the study of these relationships in the field.

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