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Development of containerized *Picea abies* (L.) Karst. seedlings grown with heavy watering on various peat, perlite and mineral wool mixtures

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Application. The development of containerized Norway spruce seedlings was strongly affected by the growth medium used. In a system based on heavy application of nutrient solution, pure sphagnum peat and the peat mixed with perlite resulted in unsatisfactory development of the seedlings.

A mixture of peat and .25 ml ml^{-1} of hydrophobic mineral wool (peat/wool 3.1/1) is recommended under heavy watering conditions.

Abstract. Effects of growth medium physical conditions were studied. Peat and two series of peat mixed with hydrophobic mineral wool or perlite in three mixing ratios were prepared. Growth media porosities were characterized by the "standardized time method" and seedling development by measurements of stem length and fresh and dry weight.

Seedlings grown in media containing mineral wool showed less mortality, were larger and had more living root apices than seedlings in media lacking mineral wool. Growth media influenced most the stem length and dry weights and was best at higher porosity. The difference between mineral wool and perlite amendments was greater for dry weight than stem length, although the effect of mixing ratio was observed for mineral wool only.

The media induced qualitative differences in shoots (foliage spiralling) and roots (branching, number of living root apices, lenticel intumescence).

Introduction

Containerized conifer seedlings grown in Norwegian forest nurseries are disturbed by a root dieback of varying severity (Venn 1985). In some cases the damage is caused by the climatic conditions, while in other cases the participation of pathogens may be suspected (Galaaen and Venn 1979).

More fundamental problems in the seedling production like restricted gas exchange in the rhizosphere have been indicated (Langerud 1985). O_2 deficiency leads to leaf epinasty, chlorosis and abscission, decreased stem and root growth, formation of lenticel intumescence (hypertrophy), increased root mortality and increased susceptibility to pathogen attack (Hook and Scholtens 1978, Sena Gomez and Kozlowski 1980, Kawase 1981, Tripepi and Mitchell

1984). The symptoms observed (Venn 1985) and the observation that 7% of the pots in a commercial nursery had less than .05 ml ml^{-1} gas filled pores after one year in production (Langerud and Sandvik in prep.) led to studies on the dynamics of the physical properties of growth media. In a simulated routine the volume fraction of gas filled pores decreased from .19 ml ml^{-1} to .07 ml ml^{-1} during 5-95 days in a mixture of peat and .25 ml ml^{-1} perlite (Langerud 1986).

Due to the great individual variation in water consumption between seedlings, heavy irrigation has been recommended to satisfy the fastest growing ones. This has resulted in unsatisfactory growing medium gas exchange conditions for a number of seedlings.

Both peat and peat-perlite mixtures have been used as growth media. Experiments at a practical nursery level revealed great problems in the local preparation of peat and perlite mixtures. The varying mixing ratios obtained and the uncertainties with respect to the effect of perlite (Haynes and Goh 1978, Prasad 1979, Verdonck 1984), initiated laboratory experiments with other growth media. We were looking for growth media satisfying gas exchange requirements for a regime based on high irrigation, and for a reduced dependence on a precise mixing ratio and varying peat quality.

The present experiment was made to evaluate a series of growth media with respect to waterlogging in a heavy irrigation regime. For the purpose of *in situ* characterization of the physical properties of growth media, a simple method was investigated (Langerud 1986). The method is based on infiltration of water through the pores of a medium, brought to a defined state by external suction. In this "standardized time method" the time needed to infiltrate a given volume of water, standardized by the volume of growth medium, is measured.

Materials and methods

Using the standardized time method, growth media were chosen to differ in physical properties when subjected to 4 kPa external suction (Langerud 1986). The series included seven growth media, one was low humified sphagnum peat, with about 65% of the dry weight as particles >1.6 mm. Few particles $<.4$ mm were found. Other information on physical properties of the peat and references to perlite and mineral wool producers were given by Langerud (1986).

Mixtures of peat and different volume fractions of perlite or hydrophobic mineral wool were prepared (Table 1). The volume fraction of the inorganic components was estimated on 24 samples of each medium as described by Langerud (1986), and the media are referred to by their peat/inorganic

Table 1. Some characteristics of Norway spruce seedlings grown with heavy watering for 147 days in various peat, perlite and mineral wool mixtures.

Medium		Inorganic compounds in the medium	Stem length	Dia-meter	Dry weight shoot	Dry weight root	Morta-lity	Without foliage spiralling	Living root apices[2]	Without visual lenticels
		$ml\ ml^{-1}$	cm	mm	mg	mg	(%)	(%)	(%)	(%)
Peat		–	4.8 a[1]	.8 a	195 a	56 a	25	72	38	62
Peat/	3.8/1	.208 ±.004	6.9 b	1.1 b	228 a	78 a	19	69	55	55
perlite	2.0/1	.334 ±.023	8.0 c	1.2 b	254 a	86 a	10	89	46	55
	1.6/1	.391 ±.012	11.5 d	1.8 c	358 a	119a	5	86	59	30
Peat/	3.1/1	.251 ±.012	22.1 f	2.9 e	1372 d	327 c	0	99	93	19
mineral	2.0/1	.330 ±.015	19.3 e	2.5 d	1183 c	290 c	0	96	73	23
wool	1.1/1	.475 ±.017	19.7 e	2.7 de	920 b	237 b	0	97	62	27

1) Mean values with different letters were significantly different (5% level) in a Duncan's range test.
2) More than 80% of the root apices alive.

component volumetric ratio. Infiltration was measured in 18 pots, without seedlings, for each medium after 147 days, by the standardized time method. The media surface was usually covered by algae or bryophytes and the effects on infiltration were evaluated before and after removal of the surface layer.

Multipot containers from commercial nurseries were used in the experiment. Each multipot unit, 30×40 cm, made from black PVC, contained 95 pots, 8.3 cm deep and with a total volume of approximately 47 ml. The pots were arranged in five rows of 11 pots alternating with four rows of 10 pots.

In each row the seven media were randomly distributed, thus occupying the first seven pots in each row. This gave nine pots of each medium in each contatiner, all of which were sown. Of the remaining pots two were filled with each medium at random and left unsown. A total of nine multipot containers were prepared this way and placed three by three in three different growth chambers.

All continous variables were checked for effects of container and chamber through analysis of variance (Goodnight 1979). No significant effects appeared, and the results were recalculated according to a model of free randomization.

Before sowing, the media were kept saturated with deionized water for three days. Norway spruce [*Picea abies* (L.) Karst.] seed from eastern Norway (elevation 150-250 m) was germinated in the containers and grown under 20 h photoperiods (400 μmol m^{-2} s^{-1}). The temperature regime averaged 24°C during the photoperiod, but decreased to 16°C at night.

The nutrient solution was prepared with deionized water and laboratory grade chemicals in proportions similar to those of Ingestad (1959). Each day, for 147 days, all multipot containers were left in nutrient solution for 45 min. The liquid surface was kept at 15 mm below the media surfaces. Nutrient solution was aerated once a week. Deionized water was percolated once a week to counteract accumulation of salts on the media surfaces.

root collar diameter, fresh and dry weight of shoots and roots were measured (sample size 61-82), and notes made on the general appearance (sample size 13-27). These notes included ocular evaluation of root morphology, color, living root apices and the presence of lenticel intumescense (Tripepi and Mitchell 1984). The shoots were inspected for visual symptoms, such as shortened, dense foliage, discoloration or otherwise abnormal appearance.

The smaller sample of seedlings was used for chemical analyses. Total concentration in the foliage of Na, Mg, Ca, Mn, Fe, Cu and Zn was analysed by routine methods (Ogner and others 1984).

Results

The porosity of the growth media, characterized by the standardized time method after 147 days in pots without a seedling is shown in Figure 1. The values were obtained after the removal of all surface vegetation, which increased the values 1.25 times at the most (peat/perlite 3.8/1).

The values were low for media made of peat and mineral wool. The higher values were found for peat and peat/perlite 3.8/1. Infiltration times were consistently higher for peat and perlite compared to peat and mineral wool mixtures.

Seedling mortality (Table 1) was high when grown in peat and peat/perlite 3.8/1, and zero in the peat and mineral wool mixtures.

The ranking of the media with respect to stem length was independent of time. Hence, stem length measured only at day 147 is given in Table 1.

The seedlings grown in peat, reached a stem length of 5 cm. The tallest seedlings were grown in peat/mineral wool 3.1/1. Seedlings grown in media containing mineral wool were significantly taller than any seedlings grown in media containing perlite. Within the peat and perlite mixtures, the stem length

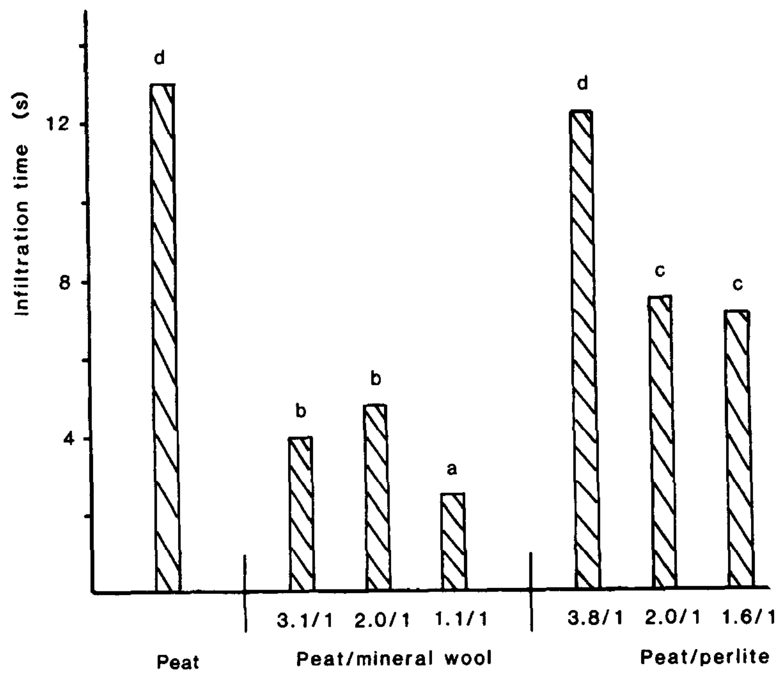

Figure 1. Mean infiltration time(s) at day 147 for different growth media. The volume ratios of peat is given inorganic component below each bar. Mean values with different letters were significantly different (5% level) in a Duncan's range test.

increased significantly with increased perlite content, while an increased mineral wool content tended to decrease the stem length.

The mean stem diameter (Table 1) ranged from .9 mm (peat) to 2.9 mm (peat/mineral wool 3.1/1) and was ranked with respect to growth media as was stem length.

Seedlings grown in the different media could be classified into three groups by dry weight. Root and shoot dry weights were not significantly different between seedlings grown in peat and in peat and perlite mixtures (Table 1). The higher dry weight was for seedlings grown in peat and mineral wool mixtures at the low mineral wool content. Intermediate dry weights were recorded for seedlings grown in the media with the higher content of mineral wool.

The most striking abnormality noted on shoots, was a growth medium dependent frequency of seedlings showing foliage spiralling (Table 1). The symptom was similar to the shoot apices spiralling associated with growth cessation, although the spiral growth in the present case comprised the greater part of the seedling, as the phenomenon continued during shoot elongation.

Peat mixed with the low fraction of perlite supported seedlings with the lowest frequency of "normal" appearance. A tendency towards decreased frequency of "normal" looking seedlings from the high to low fraction of perlite to peat was noticed. A few seedlings grown in media containing mineral wool were observed with foliage spiralling.

The root systems were classified into two basic groups with respect to morphology. The first group included seedlings grown in peat and peat mixed with perlite. These roots were poorly branched, thinkened and of a light brown color. As a rule, the number of living root apices was small (Table 1), and concentrated in the upper two thirds of the pot. The growing root apices were thickened, yellowish and club shaped with a tendency towards necrotic spots randomly spread. The second root morphology group comprised of seedlings grown in peat and mineral wool media. The color of these roots was deep brown, almost black on the distal parts, with white, transparent root apices. The roots occupied the volume of growth medium and were inhibited by air pruning at the containers bottom. These roots appeared quite similar to roots from hydroponic cultures, with dense clusters of long, thin growing roots.

The frequency of seedlings with more than 80% of the root apices alive was highest in the peat/mineral wool mixtures, but decreased with increased content of mineral wool (Table 1). The lowest frequency of seedlings with more than 80% of the root apices alive was found in peat. For seedlings grown in media made of peat and perlite, the frequency of seedlings with more than 80% of the root apices alive, was intermediate and hardly affected by perlite content.

Table 2. Concentration of selected elements in the foliage of Norway spruce seedlings grown with heavy watering for 147 days on various growth media[1]

	Concentration in foliage (mmol kg^{-1})						
Inorganic component[1]	Ca	Mg	Mn	Fe	Zn	Cu	Na
None[2)]	91.8	58.6	6.0	.70	.49	.13	3.3
Mineral wool	184 ±2.6[3)]	69.8 ±1.2	8.9 ±.24	.83 ±.03	.38 ±.01	.17 ±.01	11.4 ±2.3
Perlite	65.5 ±2.0	57.5 ±.80	4.9 ±.11	.70 ±.08	.46 ±.01	.20 ±.01	3.0 ±.36
Ingestad (1959)	47	45	–	1.3	–	–	–
Bergmann and Bergmann (1985)	100-170	40-80	.9-5.5	–	.2-.5	.08-.20	–

1) Concentration of elements was independent of mixing ratio. Mean concentration was different for inorganic component only.

2) No inorganic component refers to peat. The foliage dry weight was sufficient for a single analysis only.

3) Mean concentration and standard error of nine (mineral wool) or three (perlite) replications.

Lenticel intumescence appeared on root fractions from the upper 10-15 mm of the growth media. Seedlings grown in peat and the mixtures of peat and small fractions of perlite, had the highest frequency of roots without visible lenticels (Table 1). A low frequency of seedlings without visible lenticels was found in media made of peat and mineral wool and peat/perlite 1.6/1.

The concentration of Ca, Mg and Mn was influenced by the inorganic component of the rooting medium with significantly higher concentration in seedlings grown in media containing mineral wool (Table 2). The foliar concentration of Ca in seedlings grown in media containing perlite was below the "sufficiency level" suggested by Bergmann and Bergmann (1985), but well above the level of Ingestad (1959). The concentration of Fe was generally low, while all other element concentrations were in the range regarded as sufficient.

Discussion

A matter of concern was the high degree of coupling between physical properties and the type of amendment used. The group of media with the high porosities were all mixtures of peat and mineral wool, while the low values were in mixtures of peat and perlite. Physical properties related to the medium but not estimated by the standardized time method may have influenced the seedling development (Goh and Haynes 1978). The measurements were made in pots without a seedling, and the porosities should be higher with a seedling present (Nash and Laiche 1981).

The inorganic component of the medium influenced chemical composition of the foliage, although mineral wool (Verwer and Welleman 1980) and perlite (Joiner and Conover 1965) were supposedly "inert" materials. Mineral wool was found to release small amounts of Ca, Mg, Fe and Mn (Virolainen 1977, Sonneveld 1980).

The Fe concentration in the liquid phase of peat/perlite and peat/mineral wool mixtures was considerably lower than in the input nutrient solution (Langerud unpublished). The low concentration of Fe in the foliage of seedlings from the present study (Table 2) probably reflected this observation.

The concentration of Ca was always above the deficiency limit set by Ingestad (1959), but in seedlings grown in peat and perlite mixtures the Ca concentration was below the level recently suggested as sufficient (Bergmann and Bergmann 1985). However, symptoms of Ca deficiency (Baule and Fricker 1970) were never observed.

The differences in root morphology may reflect differences in medium physical properties like compaction and strength. The roots bore similarities to well aerated (peat and mineral wool) and flooded (peat, peat and perlite) roots, as described for *Nyssa sylvatica* (Walt.) Sorg. and *Nyssa aquatica* (L)

(Hook and Scholtens 1978). Roots of *Lolium perenne* (L) were more coarse and less dense when grown in perlite compared to a sandy loam (Jackson 1974). Roo (1977) observed O_2 deficiency in roots of *Kalmia latifolia* L. grown in a mixture of peat, sand and perlite.

Perlite can absorb a maximum of 1.6 g water g^{-1} (Verdonck 1984). Hydrophobic mineral wool held insignificant volumes of liquid, and a successful mixing with peat should create liquid free "drains" in the highly liquid absorbing peat. This effect was less likely with perlite as an amendment. With the "continuity break" (Whitcomb 1979) in mind, the gas diffusion in the lower part of a peat and perlite mixture may be negligible. The number of living root apices, the positive relationship between growth and porosity and earlier observation of the changes in physical properties of peat based media with time (Nash and Laiche 1981, Langerud 1986) further suggested a significant effect of gas exchange properties on seedling growth in this study. Spruces are considered susceptible to low rhizosphere O_2 supplies (Coutts and Philipson 1978).

The presence of seedlings with lenticel intumescence (Table 1) when grown in peat and mineral wool media, suggested that their roots were not well aerated. Development of lenticel intumescence is a hypertrophic reaction (Hook and Scholtens 1978) as a response to reduced O_2 tension in the rhizosphere and is usually associated with flood tolerance (Tripepi and Mitchell 1984). The lenticel intumenscence formation was probably a result of the daily subirrigation with nutrient solution. The dissolved O_2 in the nutrient solution was found to be exhausted during 30 min to 7 h in studies on cotton and pumpkin (Vartapetian and others 1978). The time needed for exhaustion was obviously depending on species, root weight and volume of nutrient solution.

The foliage spiralling resembled epinastic reactions observed as a response to O_2 deficiency (Kawase 1981). The symptom, spiral twist of newly formed needles, was similar to initial symptoms described as Cu deficiency in nursery grown *Picea sitchensis* (L.) seedlings (Benzian and Warren 1956). The hypothesis of Cu deficiency was not supported by further symptom development or foliar analysis for Cu (Table 2).

For growth media under a heavy watering regime, small additions of mineral wool to peat improved the rhizosphere gas exchange significantly. However, the need for an evaluation of seedlings grown in such a medium with respect to transportation and field performance is still needed.

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