Ann. For. Sci. 60 (2003) 757–762

DOI: 10.1051/forest:2003070

Original article

Survival and growth of *Abies nordmanniana* in forest and field in relation to stock type and root pruning prior to transplanting

Lillie ANDERSEN[a]*, Niclas Scott BENTSEN[b]

[a] Danish Institute of Agricultural Sciences, Department of Horticulture, Kirstinebjergvej 10, PO 102, 5792 Aarslev, Denmark
[b] Danish Forest and Landscape Research Institute, Department of Forestry, Hoersholm Kongevej 10, 2970 Hoersholm, Denmark

(Received 3 June 2002; accepted 30 October 2002)

Abstract – Bare-rooted seedlings of *Abies nordmanniana* (three stock types) were root-pruned prior to planting to evaluate the importance of stock types and root size on subsequent survival and growth after transplanting under forest and field conditions. Survival, height, root-collar diameter and dry weight (DW) of shoots and roots were compared to those of unpruned controls after two growing seasons. Transplanting in the forest significantly reduced growth in terms of plant DW, but increased height. Severe pruning of the root system reduced survival, increment in height and DW significantly. A positive relationship between height increment and initial ratio between root and shoot was found. Unpruned 2 + 2 seedlings maintained their initial advantage in terms of height, whereas the difference between 2 + 1 seedlings and 3 + 0 seedlings was small two years after transplanting.

dry weight / height / root:shoot ratio

Résumé – Survie et croissance d'*Abies nordmanniana* en forêt et au champ par rapport à la dimension des semis et à un élagage des racines antérieur à une transplantation. Les racines de jeunes semis d'*Abies nordmanniana* ont été taillés avant plantation afin d'évaluer l'importance de la dimension des plants et des racines par rapport à la survie et à la croissance, après transplantation dans les conditions de forêt de pleine terre. Après deux saisons de croissance, la survie, la hauteur, le diamètre au collet et le poids sec des pousses et des racines ont été comparés avec ceux des plants du traitement témoin. La transplantation a réduit de manière significative la croissance quant au poidss sec des plants, mais a augmenté la croissance en hauteur. Une taille sévère du système racinaire a réduit de manière significative la survie, l'accroissement en hauteur et le poids sec. Une relation positive entre l'accroissement en hauteur et le rapport initial entre racine et pousse a été trouvée notamment en pleine terre. Les jeunes plants non taillés transplantés en 2 + 2 ont gardé leur avantage initial quant à la hauteur, tandis que la différence entre les jeunes plants 2 + 1 et les plants 3 + 0 a été faible deux ans après la transplantation.

poids sec / hauteur / rapport racine/pousse

1. INTRODUCTION

Abies nordmanniana (Stev.) Spach. seedlings transplanted for Christmas tree production in the Northern part of Europe require rapid growth after transplanting if turnover time for production and competition from weed are to be kept to a minimum. Seedling growth is generally small during the first two years after transplanting, with the site normally an open field exposed to wind, especially during spring when transplanting takes place. The bare-rooted seedlings are root-pruned to facilitate transplanting, which can delay root and shoot growth [5], and their size at transplanting can have an important bearing on field performance, especially in competition with weed [6, 12, 20], although differences have been found between plant species [14]. Differences in stock type are often associated with differences in morphological characteristics, e.g. ratio between root and shoot, number of lateral roots, etc., and these have to be taken into consideration when the results are evaluated [14, 18, 20]. In the production of bare-rooted *A. nordmanniana*, seedlings are transplanted during the nursery phase to increase number of root apices [4], but seedlings are sometimes used which have been undercut instead. This difference in nursery production can have an influence on field performance after transplanting, because it has been found that root fibrosity is related to transplanting success [8, 15].

The purpose of this experiment was to study the effects of different site conditions in the forest and field, stock type and root pruning before transplanting on subsequent survival and growth in terms of height, root-collar diameter (RD) and dry weight (DW) of *A. nordmanniana*.

* Corresponding author: lillie.Andersen@agrsci.dk

Table I. Initial height, root-collar diameter and root and shoot DW. Values in each column followed by the same letter are not significantly different according to Duncan's multiple range test ($P < 0.05$) ($n = 20$).

Stock type	Height (cm)	RD (mm)	Shoot DW	Root DW (g/pl)		
				Control	15 cm	9 cm
2 + 2	22 a	10.6 a	23.4 a	13.1 a	10 b	7.47 c
2 + 1	14.5 c	7.5 c	8.4 c	5.68 de	4.77 ef	2.99 f
3 + 0	19 b	8.1 b	12.4 b	6.82 cd	5.7 cde	3.94 ef

2. MATERIALS AND METHODS

We studied *A. nordmanniana* (seed source Ambrolauri) seedlings that had been cultivated bare-rooted in a Danish nursery and lifted the day before the experiment. Three stock types were used: (a) 4-year-old seedlings grown for 2 years on a seedbed and transplanted in August in rows for 2 years (2 + 2), (b) 3-year-old seedlings grown for 2 years on a seedbed and transplanted in August in rows for 1 year (2 + 1), and (c) 3-year-old seedlings grown for 3 years on a seedbed in rows and undercut in July the second year in the seedbed (3 + 0). Before planting, the seedlings were root-pruned as follows: (1) control plants, approximately 21 cm long unpruned root system, (2) all roots pruned to 15 cm from the root collar, and (3) all roots pruned to 9 cm. The corresponding plant DW and initial height and RD are given in Table I. A block design was used with the three stock types as main plots and the root-pruning treatments as subplots with four replicates. The treatments were randomised within the main plots and subplots. The seedlings were planted in rows 60 cm apart and with 40 cm between seedlings. Each of the four subplots comprised 20 seedlings, i.e. ~80 seedlings in each treatment under each set of conditions.

2.1. Site conditions

Field planting was carried out on 29 April 1998 on a sandy loam at Aarslev, Denmark (55° 18' N, 10° 27' E). The seedlings were planted by hand in a groove, 8 cm wide and 30 cm deep, made by a machine. The seedlings were irrigated with sprinklers on a weekly basis in the first year, when evapotranspiration was greater than precipitation, and fertilized with granulated fertilizer consisting of nitrogen, phosphorus and potassium at a total of 112 kg N ha^{-1}, 24 kg P ha^{-1} and 144 kg K ha^{-1} divided into four applications in June, July, August and September. Weed was controlled by hand.

Forest planting was carried out on 30 April 1998. The experimental area, a clearing (approximately 1 ha) in a beech forest (80–100 years old) on the coast side 35 km east of the experimental station at Aarslev, had been used for *A. nordmanniana* removed the year previously. The experimental seedlings were planted as traditional forest planting in Denmark using a spade. A mixture of diuron and terbuthylazin sprayed the first year controlled weed, which consisted mostly of *Rubus* spp. and *Carex* spp. The seedlings were fertilized after transplanting with a total of 70 kg N ha^{-1}, 9 kg P h^{-1} and 24 kg K ha^{-1}.

After two growing seasons, the seedlings were carefully lifted in November 1999. In the field, a machine was used to lift seedlings to a depth of 40 cm in the soil. In the forest, the seedlings were lifted by hand using a spade, and although care was taken small roots may have been lost during the operation on both sites.

Table II. F-values for effect of site, stock type and pruning treatment and interactions on final root-collar diameter, height and shoot and root DW ($P < 0.05$).

	RD	Height	Shoot DW	Root DW
	F-values			
Site conditions	473.92*	30.94*	345.17*	750.47*
Stock type	47.9*	88.12*	71.23*	41.64*
Root pruning	53.74*	29.0*	59.26*	82.50*
Site*stock type	8.33*	8.15*	0.79	0.30
Stock type*pruning	2.67	10.43*	1.84	1.13
Site*pruning	5.04*	3.96*	11.98*	16.76*
Site*pruning*stock type	1.12	0.83	0.65	0.59

2.2. Analysis of plant growth

Initial height and RD of all transplanted seedlings were determined. Samples of 20 seedlings from each stock type and treatment were used to determine initial DW, height and RD (Tab. I). At the final lifting, mortality was calculated from the number of dead seedlings as a percentage of seedlings transplanted. Ten seedlings from each replicate (40 in each treatment) were used for morphological analysis. The roots were washed and the seedlings separated into shoot and roots at the base of the shoot. Height and RD were measured and DW was determined after drying for more than 48 h at 70 °C.

2.3. Statistical analysis

Analysis of the variance procedure (GLM procedure of SAS™, Anon. [2]) and comparison of means using Duncan's multiple-range test ($P < 0.05$) were carried out to evaluate the effects of site, stock type and root-pruning treatments.

3. RESULTS

3.1. Initial morphology

The 2 + 2 seedlings were superior to the other stock types in terms of height, RD, root and shoot DW (Tab. I). Transplanting and undercutting affected seedling size differently. Height, RD and DW were reduced by the transplanting process, but root:shoot ratio increased in transplanted seedlings (2 + 1) compared to undercut seedlings (3 + 0). Pruning of the roots reduced initial root DW and hence root:shoot ratio in all treatments. Root:shoot ratio was still highest in the 2 + 1 seedlings compared with the other two stock types (data not shown).

3.2. Survival

No difference was found between survivals in the forest and in the field. Root pruning had a significant negative effect on survival. When the roots were pruned to 9 cm, 23%, 10% and 13% of seedlings transplanted in the field as 2 + 2, 2 + 1 and 3 + 0, respectively, died. In the unpruned controls, the percentages of dead seedlings were 3%, 0% and 5% in the three stock types.

3.3. Height

Final height was affected more by stock type than by planting site or pruning treatment (Tab. II). Height increment of control

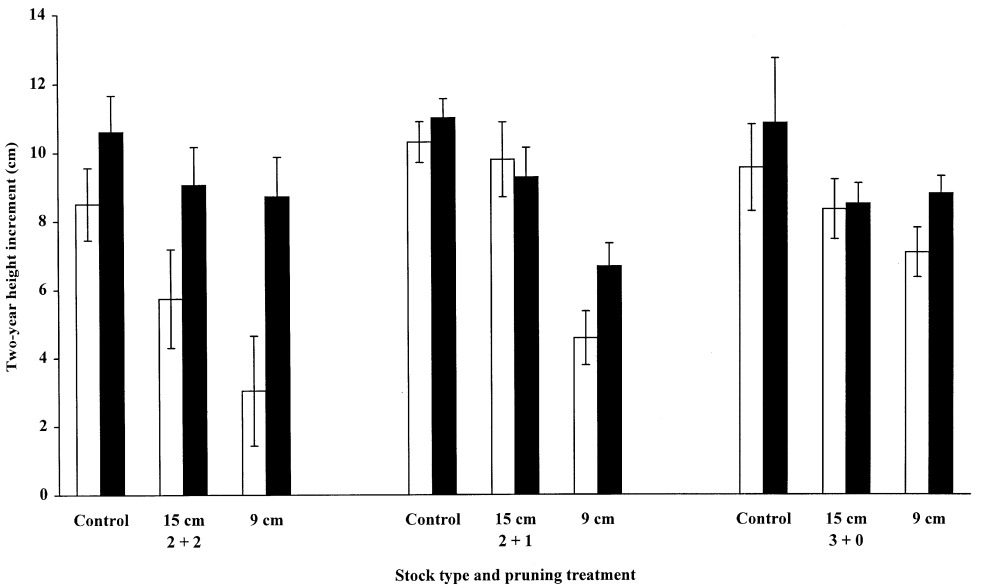


Figure 1. Height increase in relation to site conditions (field = open, forest = black), stock type and root-pruning treatment after two growing seasons. Error bars represent standard deviation.

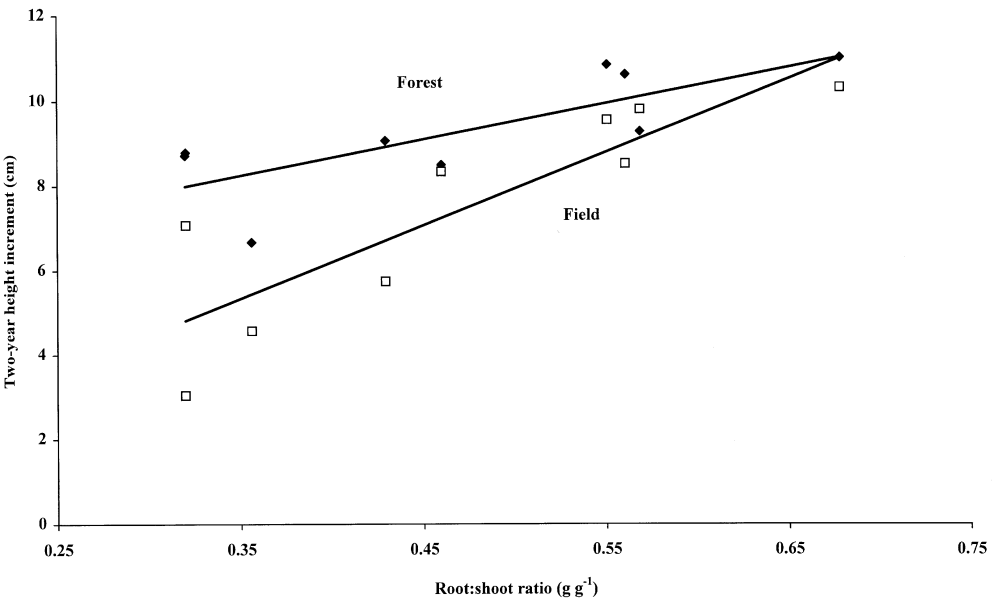
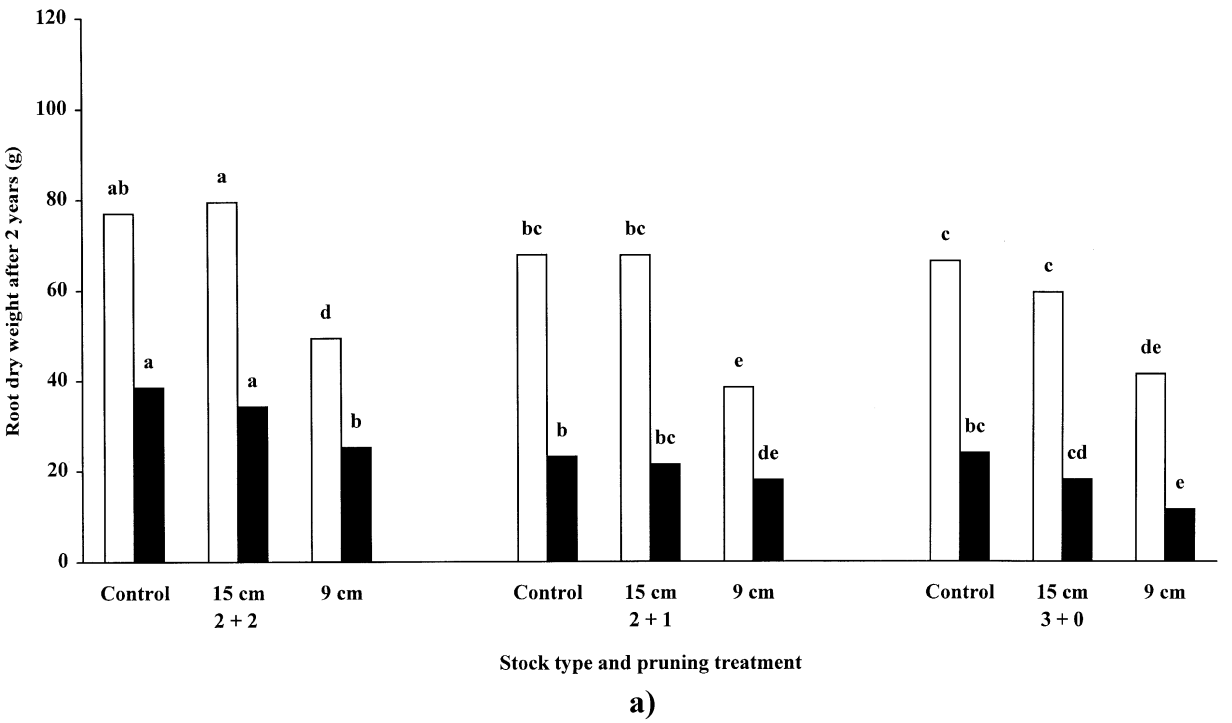


Figure 2. Height increase in the field (open) and forest (black) in relation to initial root:shoot ratio of all stock types and prunings (forest = $8.45 \times x + 5.3$; $r^2 = 0.596$; field = $17.28 \times x - 0.71$; $r^2 = 0.747$).

seedlings after 2 years was significantly ($P < 0.05$) greater in the forest than in the field (Fig. 1). Pruning of the roots before planting lowered height increment relative to severity of pruning. The 2 + 2 seedlings reacted more negatively to the pruning treatment in the field compared to the other stock types. A positive relationship between initial root:shoot ratio and height increment could be found (Fig. 2).

3.4. Final RD and DW of root and shoot

The site significantly affected RD (Tab. II) and interactions were found. The difference in root DW between field and forest transplanting was pronounced (Tab. II and Fig. 3a). In the field, the increased root DW constituted from 5 to 13 times that of initial root DW, whereas in the forest the increase was



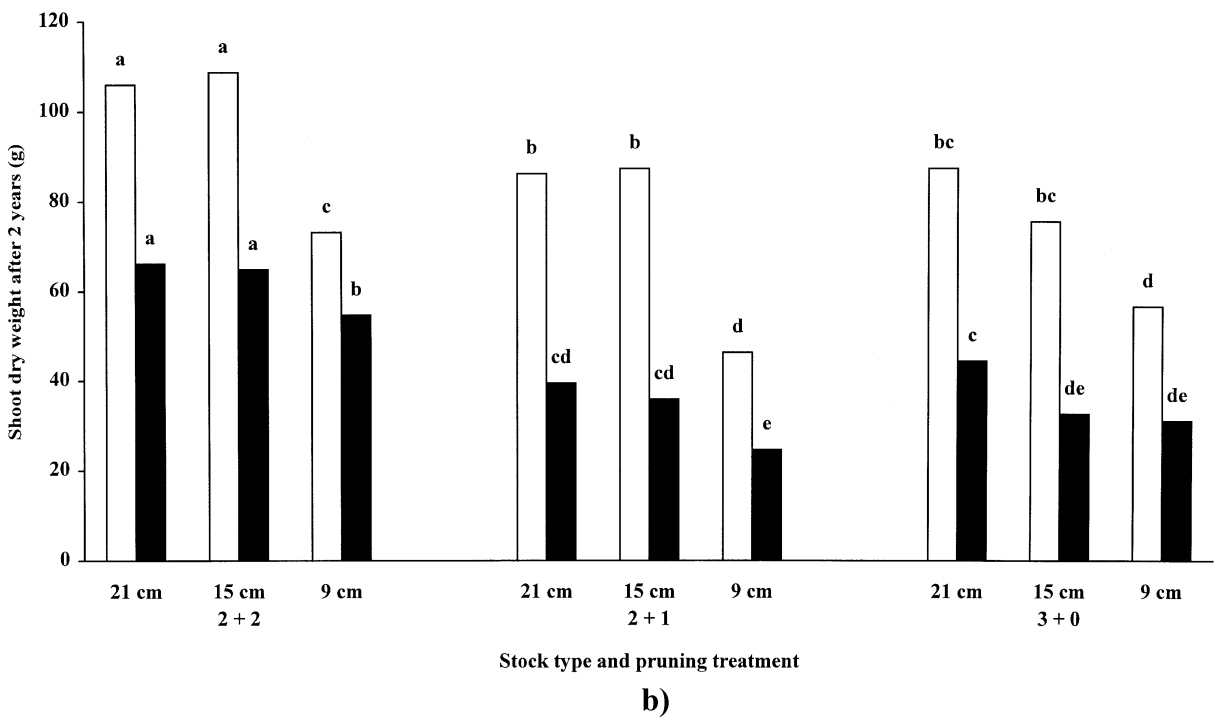


Figure 3. (**a**) Final root DW two years after transplanting in relation to site conditions (field = open, forest = black), stock type and root-pruning treatment. Columns followed by the same letter within each set of conditions are not significantly different according to Duncan's multiple range test ($P < 0.05$). (**b**) Final shoot DW two years after transplanting in relation to site conditions (field = open, forest = black), stock type and root-pruning treatment. Columns followed by the same letter within each set of conditions are not significantly different according to Duncan's multiple range test ($P < 0.05$).

from 2 to 5 times. Pruning the roots to 9 cm significantly reduced growth in terms of root DW in all three stock types (Tab. II and Fig. 3a). Pruning to 15 cm did not affect root DW. Stock type had less effect than root pruning on final root DW, and no interaction between stock type and site or pruning was found (Tab. II).

Shoot growth in terms of DW displayed similar reactions as root growth (Fig. 3b). Again site had a pronounced effect on the increment in shoot DW, as shoot DW was increased by 2 to 9 times that of initial shoot DW in the field and 0.35 to 4 times in the forest. Stock type had a greater effect on final shoot DW than pruning treatment; however, interactions were found between site and pruning on shoot DW (Tab. II).

The larger increase in root DW compared to shoot DW was reflected in an increase in root:shoot ratio, except for control seedlings planted in the forest (data not shown).

4. DISCUSSION

4.1. Forest and field performance

Survival was generally high both in the forest and the field. Root pruning reduced survival, just as in other species [5]. When the large stock type, 2 + 2, was pruned heavily to 9 cm, survival was reduced in the field, probably because the pruning process at planting lowered the ratio between root and shoot.

Height increment in the forest was greater than in the field; this effect of transplanting site might be a response to light quality i.e. ratio between red and far-red light [3]. Performance in terms of DW was lower in the forest than in the open field. The difference between the two sites was so large that differences in access to photosynthetic light are probably responsible. The results suggest that *A. nordmanniana* seedlings react to limitations in light during the early transplanting phase.

Physical restrictions in root growth in the forest could be responsible for some of the effects because of transplanting using a spade. Competition below ground for nutrients and water has been suggested as reducing growth in conifer seedlings [13, 17]. Generally, however, root growth and root:shoot ratio are increased when nitrogen and water are limited, at least in the early period after transplanting [7, 9, 19, 20]. Under field conditions, there were no limitations, and access to nutrients and water could be used for root and shoot growth.

4.2. Root pruning

Height increment was relatively small in all treatments and lower in proportion to severity of pruning, as found in other species [5]. In studies conducted by Deans et al. [8] and Bigras [5] in *Picea*, root pruning decreased the final DW of root and shoot. It is likely that root growth potential was decreased with the removal of root apices during the pruning process [8]. In addition, development of new roots in conifer seedlings depends on current photosynthesis, which might be reduced when seedlings have been root pruned [16, 19]. Severe root pruning of conifer seedlings prior to transplanting should therefore be avoided [1]. In the present experiment, L-shaped roots were found when unpruned seedlings were transplanted in the forest using a spade. Still, the unpruned root system had a positive effect on plant growth compared to severely pruned seedlings, whereas a limited pruning to 15 cm had no effect on DW compared with control, except on shoot DW in 3 + 0 seedlings planted in the forest.

4.3. Stock type

Initial RD has been proposed as an indicator of tree performance, although differences between plant species have been found [14]. Mason et al. [10] found a good correlation between RD and tree performance, with RD increasing from 4 to 6 mm. When it comes to larger seedlings, as in the present experiment, the effect of RD declines, as seen in recent studies by Mason [11].

In Denmark, 2 + 2 seedlings are normally used for transplanting; the results show that this stock type is still the largest at the end of the experiment when the roots are not pruned prior to transplanting.

5. CONCLUSION

Transplanting *A. nordmanniana* in the forest increased height growth, but decreased growth in DW of both root and shoot. A positive relationship between the initial root and shoot ratio and height increment after transplanting was found. The results indicate that growth of *A. nordmanniana* seedlings are to be increased when they are not severely root-pruned prior to transplanting.

Acknowledgements: The technical help from Kirsten van Dam and Liliane Aolio with the translation to French is thankfully acknowledged.

REFERENCES

[1] Andersen L., Survival and growth of *Fagus sylvatica* seedlings root-pruned prior to transplanting under competitive conditions, Scand. J. For. Res. 16 (2001) 318–323.

[2] Anon., SAS/STAT™ Guide for personal computers, Version 6 edition, SAS Institute Inc., Cary, NC, USA, ISBN 1-55544-064-9, 1987, 1028 p.

[3] Aphalo P.J., Ballaré C.L., Scopel A.L., Plant-plant signalling, the shade-avoidance response and competition, J. Exp. Bot. 50 (1999) 1629–1634.

[4] Atzmon N., Reuveni O., Riov J., Lateral root formation in pine seedlings. II. The role of assimilates, Trees 8 (1994) 273–277.

[5] Bigras F.J., Field performance of containerized black spruce seedlings with root systems damaged by freezing or pruning, New For. 15 (1998) 1–9.

[6] Britt J.R., Mitchell R.J., Zutter B.R., South D.B., Gjerstad D.H., Dickson J.F., The influence of herbaceous weed control and seedling diameter on six years of loblolly pine growth – a classical growth analysis approach, For. Sci. 37 (1991) 655–668.

[7] Davis M.K.A., Wrage K.J., Reich P.B., Tjoelker M.G., Schaeffer T., Muermann C., Survival, growth, and photosynthesis of tree seedlings competing with herbaceous vegetation along a water-light-nitrogen gradient, Plant Ecol. 145 (1999) 341–350.

[8] Deans J.D., Lundberg C., Cannell M.G.R., Murray M.B., Sheppard L.J., Root system fibrosity of Sitka Spruce transplants: Relationship with root growth potential, Forestry 63 (1990) 1–7.

[9] Krasowski M.J., Owens J.N., Tackaberry L.E., Massicotte H.B., Above- and below-ground growth of white spruce seedlings with roots divided into different substrates with or without controlled-release fertilizer, Plant Soil 217 (1999) 131–143.

[10] Mason E.G., South D.B., Weizhong Z., Performance of *Pinus radiata* in relation to seedling grade, weed control, and soil cultivation in the central north island of New Zealand, N. Z. J. For. Sci. 26 (1996) 173–183.

[11] Mason E.G., A model of the juvenile growth and survival of *Pinus radiata* D. Don, New For. 22 (2001) 133–158.

[12] McGrath D.A., Duryea M.L., Initial moisture stress, budbreak and two-year field performance of three morphological grades of slash pine seedlings, New For. 8 (1994) 335–350.

[13] Nilsson U., Gemmel P., Hällgren J.-E., Competing vegetation effects on initial growth of planted *Picea abies*, N. Z. J. For. Sci. 26 (1996) 84–98.

[14] Noland T.L., Mohammed G.H., Wagner R.G., Morphological characteristics associated with tolerance to competition from herbaceous vegetation for seedlings of jack pine, black spruce, and white pine, New For. 21 (2001) 199–215.

[15] O'Reilly C., Harper C.P., The morphological characteristics, root growth potential and flushing response of rooted cuttings compared with transplants of Sitka spruce, Ann. For. Sci. 56 (1999) 201–210.

[16] O'Reilly C., McCarthy N., Keane M., Harper C.P., Gardiner J.J., The morphological status of Douglas fir seedlings and the field performance of freshly lifted and cold stored stock, Ann. For. Sci. 56 (1999) 297–306.

[17] Seith B., George E., Marschner H., Wallenda T., Schaefer C., Einig W., Wingler A., Hampp R., Effects of varied soil nitrogen supply on Norway spruce (*Picea abies* (L.) Karst.). I. Shoot and root growth and nutrient uptake, Plant Soil 184 (1996) 291–298.

[18] South D.B., Mitchell R.J., Determining the "optimum" slash pine seedling size for use with four levels of vegetation management on a flatwoods site in Georgia, USA, Can. J. For. Res. 29 (1999) 1030–1046.

[19] van den Driessche R., Importance of current photosynthate to new root growth in planted conifer seedlings, Can. J. For. Res. 17 (1987) 776–782.

[20] van den Driessche R., Nursery growth of conifer seedlings using fertilizers of different solubilities and application time, and their forest growth, Can. J. For. Res. 18 (1988) 172–180.