LITERATURE CITED

Appleton, B.L. 1995. New nursery production methods lead to tree root circling reduction or elimination. Arboricultural J. 19:161-174.

Arnold, M.A. 1994. Transplanting experiments: what worked and what did not, pp 34-46. In: G.W. Watson and D. Neely (eds). The landscape below ground. Proceedings of an international workshop on tree root development in urban soils. Intl. Soc. Arboriculture, Savoy, Illinios,

Arnold, M.A. and **G.V. McDonald.** 1999. Accelerator containers alter plant growth and the root zone environment. J. Environ. Hort. 17(4):168-173.

Harris, R.W. 1967. Factors influencing root development of container grown trees. Proc. 43rd Intl. Shade Tree Conf. pp. 304-314.

Lawry, D. and **J. Gardner.** 2001. Treenet. Pilot study of street tree planting in South Australia. Horticulture Australia. Project number: NY00042.

May, P.B. 2002. The evolution of container design. Comb. Proc. Intl. Plant Prop. Soc. 52 (in press).

Smith, K.D. and **P.B. May.** 1997. Root growth in difficult conditions – Between a rock and a hard place! Trees - Roots - Soils, Managing the Interaction. pp. 17-25. Burnley College, Melbourne.

Struve, D.K., M.A. Arnold, R. Beeson, J. Ruter, S. Svenson, and **W.T. Witte.** 1994. The copper connection. Amer. Nurseryman 179(4):52-56.

Whitcomb, C.E. 1988. Plant production in containers. (revised ed.) Lacebark Publications, Stillwater, Oklahoma.

Root Deformation in Plantations of Container-grown Stock: Consequences for Growth, Stability, and Stem Quality©

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INTRODUCTION

During the 1970s many forestry nurseries in Scandinavia changed from bareroot to containerised plant production. In the late 1970s we received the first alarming reports about poor stability and root development in plantations of container-grown plants. Since then several different types of container systems have been introduced to the market, and a number of these systems cause more or less strong root deformation.

The consequences of root deformities are complex and can in the long term lead to significant economic losses. Root deformities can affect the growth, stability, and stem straightness of young stands. Poorer tensile strength and internal deformities increase the risk of fibre breakage, which increases the risk of fungal attacks, primarily on the root system. Once the trees vitality is reduced, the risk of fungal attacks on stems or shoots also increases.

The ultimate result of root deformities is that the tree falls over and dies because impeded root development results in poor anchorage of the tree. The tree can also break at the stem base.

DEVELOPMENT IN CONTAINER DESIGN

In the 1970s the dominating container types were Kopparfors and Paperpot containers. These containers caused a special type of root deformity, root spiraling, which occurs in container systems with smooth inside walls. These container types were generally abandoned in the beginning of the 1980s. A development in container design, the introduction of guiding ribs and later air slots in the sides of the containers, during the 1980s and 1990s has led to a new generation of very open containers. These are designed to prevent root deformities in the young plants.

These new systems all have root pruning in common. The pruning of roots is either by air-pruning, as mechanical pruning, or chemical pruning. Several studies have shown the significance of root guidance (by, for example, ribs or star-formed cavities) and correct root pruning in order to prevent root deformities in containerised stock.

A survey study performed by Lindström and Håkansson in 1995 on root form of pine seedlings grown in different container types clearly showed that root control through a process of air (Jiffy) and/or mechanical root pruning (Plant System 80) was effective (Table 1).

TIME IN CONTAINER

One factor that is contributing to the severe root deformities seen in plantations is that the plants have been grown for too long in containers that are too small. This is possibly still a problem in many nurseries worldwide. The root deformities increase significantly with time, and this is particularly the case in the old style containers without root guidance. The root form photographs (Fig. 1) show that Jack pine (*Pinus banksiana*) seedlings with juvenile rooting systems in fragile plugs (which are not yet root bound) formed "natural" root form when planted and that the deformations increased with increased time in container. Black spruce (*Picea mariana*) in open-walled mesh containers showed better root forms even after a relatively longer nursery rearing.

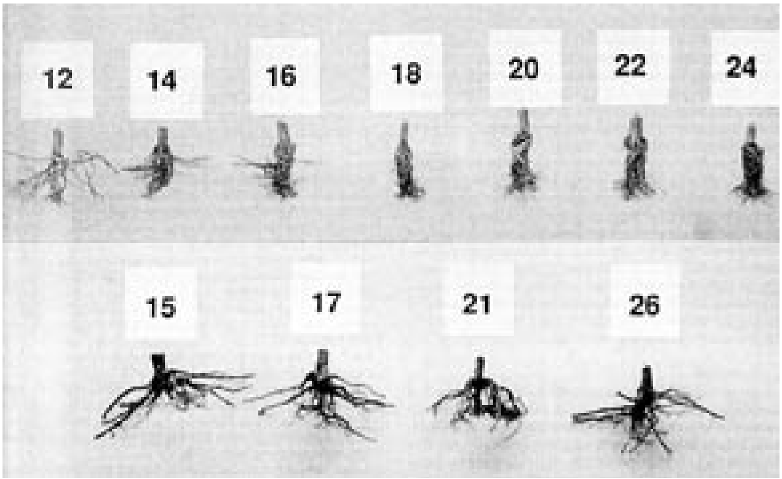

Figure 1. Roots of Jack pine grown in a conventional-walled cavity system (top row) and black spruce from a free standing mesh covered plug system (Jiffy™) (bottom row) after three field seasons. Extended roots were gathered together and cut approximately 5 cm below the bottom of rearing soil plug before washing. Numbers represent weeks grown in the nursery before planting out (Salonius 1993, unpublished, In: Balisky et. al. 1995).

Table 1. Root deformities in different container systems. Scots pine seedlings delivered from nurseries in the autumn 1994.

	Container wall	Date of sowing	Proportion of seedlings with twisted roots[X] (%)				Upward growing roots (per plant)(no.)
			None	Negligible	Moderately	Severely	
Jiffy-7	Open, mesh	June 28	100.0	0.0	0.0	0.0	0.0
Plant System 80	Slots	May 18	86.7	13.3	0.0	0.0	0.1
BCC-side slit	Ribs/slots	May 1	0.0	46.7	46.7	6.6	5.0
Plantek	Ribs/slots	May 1	0.0	60.0	40.0	0.0	3.5
Blockplant 10x10	Ribs	May 1	13.3	60.0	26.7	0.0	4.4

[X] N=15.
Source: Lindström and Håkansson 1995.

Table 2. Proportion of Scots pine with straight (0-5°), slightly crooked (6-30°), crooked (31-45°) and very crooked (>46°) stem bases (Lindström and Rune, 1999).

Type of tree	Age	Proportion of stem bases (%)				Tested trees (no.)
		Straight stem base	Slightly crooked	Crooked	Very crooked	
Paperpot	7-9	37	47	13	3	90
Paperpot	19-21	38	55	5	2	100
Natural regeneration	7-9	56	42	0	2	108
Natural regeneration	22-24	75	25	0	0	20

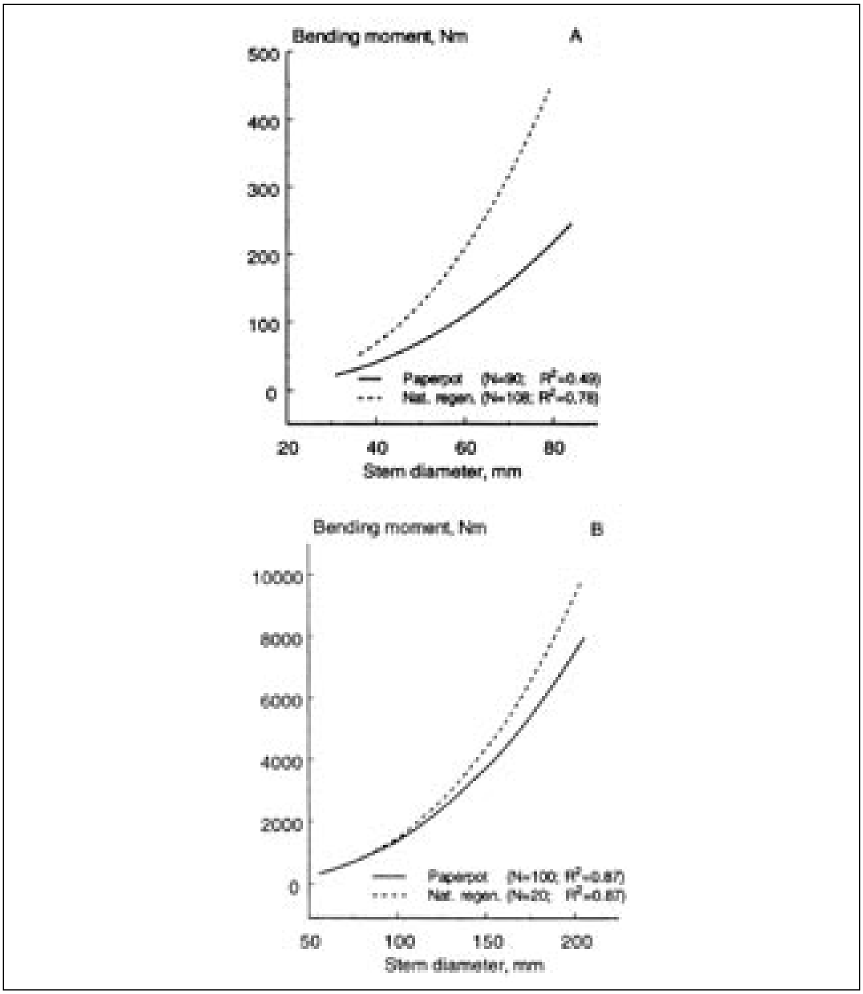

Figure 2. Relationship between stem diameter and bending moment when pulling to a 10° angle according to the function $B=e^a \times D_0{,}20^b$ (B=bending moment (Nm), D=cross callipered stem diameter at 20 cm height (mm), a and b=constants) for A) 7-9 year and B) 19 to 24-year-old naturally generated and planted Scots pine trees. Lindström and Rune, 1999.

EFFECTS OF ROOT DEFORATION

Stability and Growth. Naturally regenerated trees normally show better stability than planted trees because they have larger root areas, lack of root deformities, and a more uniform root distribution. This is in accordance with the results of Lindström and Rune (1999) where naturally regenerated and container-grown (Paperpot) Scots pine was studied. In winching tests they found that young Paperpot-grown trees were unstable as compared to naturally regenerated trees. The explanation given for this was that the planted trees had a lower root area and a less uniform root distribution than the naturally regenerated trees (Fig. 2).

For the support function of a root system it is necessary that the lateral roots grow straight out with a radial orientation from the tree. For the steadying function, it is important that the roots are large. As the root mass is dependent on the number of roots, a root system with many roots will also have small roots. It is found that an optimal bending moment is reached with 4 to 5 main lateral roots (first order).

Studies have shown that there is a strong positive correlation between the number of first order lateral roots (FOLR) of a tree seedling and its survival and growth after planting. This number is under genetic control, but can also be optimised or reduced by the choice of container system. A container system with a greater lateral root pruning effect will produce a seedling with a higher number of FOLR.

STEM STRAIGHTNESS

In the study of Lindström and Rune (1999) it was found that planted container–grown (Paperpot) trees had a higher frequency of crooked stem bases than naturally regenerated trees (Table 2). This indicates that the trees have been unstable during a period of their development and it is likely that this is related to the form of the root system.

WOOD QUALITY

A higher frequency of crooked stems due to root deformities as shown above is in itself a sign of poor timber quality. Poor timber quality could result in a lower wood capture and timber price, which again has a negative impact on the plantations total economy. Wood samples from stumps of 20-year-old container-grown (Paperpot) trees showed much lower values for tensile strength than wood samples from stumps of natural trees (Lindström and Rune, 1999). This was caused by fibre disturbances due to root deformities, and indicates an increased risk for breakage of roots in older container-grown trees.

DISEASES CAUSED BY FUNGI

Root spiralling and root compression can also increase the risk of diseases caused by fungi. A higher frequency of the destructive fungi *Armillaria* spp., in the form of rhizomorphs, is observed on planted trees compared with natural trees. Stressed trees are favoured by *Armillaria*, it spreads under the bark in parasitic attacks. The most aggressive types can lead to decreased growth and even strangulation. Studies have also shown that there is a correlation between root deformations caused by the containers in the nursery and the frequency of *Armillaria*.

CONCLUSIONS

There is a risk of root deformities in plantations caused by the container system used. These deformities have negative impacts on the growth, stability and stem quality of the future stand. The container system must be designed to prevent the lateral roots (and the tap root) being diverted by the container wall. To prevent root compression the seedlings must not be grown too long in the container. Root pruning is necessary to create a lateral root system as close to a natural root system as possible.

LITERATURE CITED

Balisky A.C., P. Salonius, C. Walli, and **D. Brinkman.** 1995. Seedling roots and forest floor: Misplaced and neglected aspects of British Columbia's reforestation effort? For. Chron. 71:59-65.

Lindström, A. and **G. Rune.** 1999. Root deformation in plantations of container-grown Scots pine trees: effects on root growth, tree stability and stem straightness. Plant and Soil. 217:29-37.

Lindström, A. 1998. Root deformations and its implications for containerised seedling establishment and future quality development [In Swedish with English summary], pp 51-60. In: C. Almqvist (ed.), Root development and stability. Conf. held at Garpenberg, Swed., 30. Sept.-1.Oct. 1997. The For. Res. of Swed. Rpt. No. 7.

Lindström, A. and **L. Håkansson.** 1995. Survey studies on root form of pine seedlings grown in different container types. [In Swedish] Work Rep. Swed. Uni. of Agr. Sciences, Dept. of For. Yield Research.

Lindström, A. and **L. Håkansson.** 1995. Going to the root of the evil. Canadian Silviculture Magazine. 3:14-17.

Nelson, W.R. 1998. Root pruning can influence first order lateral root development of containerised plants. Comb. Proc. Intl. Plant Prop. Soc. 48:96:103.

Rosvall. O. 1998. The stability mechanics of the root system is dependent on the design of the container system, pp 32-36. In: C. Almqvist (ed.), Root development and stability. Conference held at Garpenberg, Swed., 30. Sept.-1.Oct. 1997. The For. Res. of Swed. Rpt. No. 7.

Rocketpot Technology©

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RocketPot Technology helps to grow and transplant advanced trees. The RocketPot Tree Growing System (RPTGS) helps manage roots — and roots "manage" trees. The RPTGS is a modular container system with a set of recommendations for use. Together, the containers and the set of recommendations make up a better practice for growing trees. It is a candidate for "best practice".

HARDWARE

The modular container system is a family of 3D air-root-pruning pots. They are "tools for growing trees" and remain in your nursery as far as possible. They are used and re-used year after year. RocketPot growing containers are usually replaced by vending bags at the point of sale.

The containers incorporate air root pruning to open ended cusps. Dr. Carl Whitcomb demonstrated this idea in Australia in March 1988. Modern models have a 25-mm air gap below the growing medium, making it a 3D-air root-pruning device. The containers have a life expectancy of at least 5 years.

At present, RPTGS is focussed on "advanced" trees, where an advanced tree is defined as a tree with calliper of 30 to 75 mm and a height of 2 to 4 m. The RPTGS principles probably have wider application.

Tree vending bags are part of RPTGS. They are: transparent, put your root quality on show, use only 5% to 8% of the weight of plastic used in typical solid-wall containers, and designed to last for a month, but are UV stable. They can work and last for over a year in extreme circumstances.