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ROOT DEFORMATIONS OF AUSTRIAN BLACK PINE (*PINUS NIGRA* ARN.) SEEDLINGS AND TREES IN STANDS RAISED BY VAROIUS STOCK TYPE SEEDLINGS

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Abstract

In this paper, results of investigation of root systems of containerized and bare root seedlings and trees in stands of Austrian black pine in the R. of Macedonia are presented. The aim of the investigation was to analyze root morphology and deformations of 1+0 Austrian black pine (*Pinus nigra* Arn.) seedlings and trees grown in containers “Paperpot” and “Yucosad”, compared with bare root seedlings. Presence and deformations of lateral and vertical roots of the seedlings were analyzed. Investigated stands were raised by the same seedling stock types and developing in different ecological conditions. On each stand trees were excavated with root ball, cleaned, measured and analyzed. Deformities of roots and irregularities of lateral roots spreading were recorded. Indexes *R*, *HV* and *A* were calculated. Root systems of seedlings of both container types are modified and deformed by the container. Morphology and deformities of root systems of young trees of both container types are similar and the influence of primal container is still perceptible. Root systems of older trees gradually overcome this disposition and develop according to site conditions ensuring functionality and stability. Secondary deformations take part in root morphology modification of all seedling stock types. There is no significant difference between Paperpot and Yucosad seedlings and trees features, roots morphology and field performance. Container and bare root stands’ growth and vitality depend mostly on site conditions and planting technique.

Key words: bare root seedlings, container seedlings, root system, deformations, stands.

Introduction and Aim of Investigation

Aforestation with container seedlings has a long tradition worldwide. However, despite advantages of using container seedlings, problem of root deformations affecting growth of stands is observed (Volná and Mauer 1983, Stilinović et. al. 1986, Kolevska 1997, Rune 2003, Robert and Lindgren 2006 etc.). In Macedonia, the “Paperpot” container seedlings have been used since 1974, while a domestic hard-plastic container “Yucosad” has been developed few years later and is widely used ever since. However, the development of stands raised with “Yucosad” seedlings was under suspicion because of root deformations, therefore poor development, and finally dying of “Yucosad” stands at approximately 6–8 years of age, has been prognosticated, while stands raised with “Paperpot” seedlings were favoured (Popovski 1985).

Therefore, in this research the root systems of “Paperpot”, “Yucosad” and bare root seedlings and trees in stands of Austrian black pine, planted mostly within the framework of regular afforestation activities of the forest operative in the R. of Macedonia, were investigated. The aim of the investigation is to analyze morphology of root system of seedlings and trees, presence of deformities and root systems development.

Materials and Objects

1. Seedlings

There were analyzed 1+0 Austrian black pine seedlings of following stock types: "Paperpots" container (type FH 508, volume c/a 120 ml, produced by Lannen Tehtaat Oy); "Yucosad" container (hardplastic, bullet-shape with shallow 1 mm ribs, h=10 cm, upper d=3.8 cm, lower d=1.0 cm, volume=70 ml, produced in Macedonia). As control, 1+0 bare root seedlings were used.

2. Trees in stands

The investigation of trees was executed both in stands, planted during regular afforestation activities of the forest operative, and in 4 experimental fields. Total of 27 Austrian black pine stands of 4–19 years of age at 19 localities were analyzed. On each stand 11–30 trees, i.e. a total of 637 trees were measured and analyzed. Stands were raised with "Paperpot", "Yucosad" and "bare root" seedling stock types; ecological conditions: altitude 250–1340 m a.s.l.; soil: eutrical cambisol, districal cambisol, rendzina, alluvium; site preparation and planting technique: plough furrows, planting into a crevice or small hole with various planting tools.

Methods

1. Seedlings

Deformations of lateral roots, presence and deformations of central (tap, main) and vertical roots were analyzed. Eccentricity of root system was recorded (if the seed was sown out of the center of the container, an asymmetrical root system developed). Root density and knotting were evaluated. 30 seedlings of each stock type (total 90 seedlings) were analyzed.

2. Trees

From each stand 11–30 trees were excavated with root ball with diameter 30–100 cm and depth 30–60 cm and cleaned. A destructive analysis and measurement of roots, following methods of Lokvenc (1980) and Volná–Mauer (1983), adapted by Kolevska (1995) was executed. Each root system was visually divided into vertical sections (10 cm layers). A radius of rooting of 360° (horizontal distribution, i.e. spreading of the roots) was divided into four quadrants of 90° each. The direction of terrain inclination and the plouw furrow divides the quadrants. The following parameters were measured and analyzed: diameter of root collar (10 cm above the ground); number and diameter (>1 mm of trees 4–5 years of age, resp. >3 mm older trees) of horizontal skeletal roots in each quadrant of rooting and in each vertical layer; number and diameter (>1 mm, resp.

>3 mm) of vertical skeletal roots in each vertical zone; deformities of horizontal and vertical roots; deformities of the stem at the zone of the former container; irregularities and deviations of the horizontal root spreading.

A cross section area (CSA) of root collar and of each horizontal and vertical root was calculated (mm^2). Indexes R, HV and A were calculated. Index R – CSA of root collar/CSA of all skeletal roots (horizontal+vertical). Index HV – CSA of horizontal skeletal roots/CSA of vertical skeletal roots. Index A – CSA of roots of two quadrants with max values/ CSA of roots of two quadrants with min. values. Data analyses were performed using SPSS program version 20.0. Comparison of root deformities between trees of different seedling stock type was executed using Pearson's X^2 test. Significance of the indexes was tested using Mann-Whitney's U test.

Abbreviations in the text and tables: PP – Paperpot, YS – Yucosad, BR – Bare root seedlings, N – number of analyzed trees, CSA – cross section area.

Results and Discusion

1. Seedlings

Results of investigation of seedlings are presented in Table 1. Both container seedling types have similar root deformations. Primary deformations (caused by the container, Kolevska 1995) affect lateral and vertical roots. Deformities of central root were observed in lower proportion, while lateral roots were deformed in very high proportion (Fig. 1, 5). The container seedlings root systems are mostly dense and knotted (spiralled and tangled). X^2 test confirms similarities between PP and YS seedlings, except "L" root deformation of PP seedlings (generated by production mat, Fig. 1). Container seedlings, compared to bare root (Fig. 9), have significantly worse deformed root systems. Similar deformities (spiralling, knotting, "elbow" shape etc.) of PP and hard-plastic container pine seedlings record more investigators (Stilinović et. al. 1980 on *P. nigra*, Girouard 1991 on *P. banksiana,* etc.). Dominguez-Lerena et al. (2006) analyzed growth and development of *P. pinea* seedlings in different containers. All containers, including those with ribs, induced root spiralling, however there was no relationship between the number of spiralling roots and container characteristics. Root spiralling did not influenced seedling performance 3 years after outplanting (height and diameter increment and survival).

2. Trees

Results of investigation of trees in stands of each seedling type are presented in Table 2 (trees 4–5 years of age) and Table 3 (trees 7–19 years of age). Similar primary deformations, described at the respective seedling stock type, persist and were recorded at the young container-type trees (Fig. 2, 6). As a consequence of primary and secondary (generated by human factor, i.e. mostly by technique of planting) deformations, irregularities of rooting, deformations of horizontal and vertical roots were observed. Secondary deformations affect all seedling stock type trees. Bad planting technique deteriorates the initial root condition. Planted into a crevice or a small hole, roots are pressed into a plain (uni- and bilateral root system, Fig. 4, 12) or warped and twisted. Vertical

Table 1. Roots features and deformations and X^2 test, seedlings 1+0.

Seedl. stock type	Tap vertical root, %			Eccentricity of root system,%	Deform. of lateral roots in shape, %		Density of root system, %			Roots knotting, %	
	straight	deformed in shape “L”	deformed in shape “O”		“elbow”	“ring”	sparse	medium	dense	poor	strong
PP	60	37	7	50	100	80	20	20	60	60	40
YS	90	0	10	47	100	80	20	30	50	40	60
BR	100	0	0	0	0	0	40	60	0	0	0
X^2 test for root features and deformations, seedlings 1+0 (* – significance p<0.05)											
PP-YS	5.689*	11.130*	0.000	0.000	–	0.104	0.104	0.355	0.269	1.666	1.666
PP-BR	12.600*	11.130*	0.517	17.420*	56.070*	36.740*	1.984	8.403*	22.940*	22.940*	12.600*
YS-BR	1.404	–	1.403	15.750*	56.070*	36.740*	1.984	4.309*	17.420*	12.600*	22.940*

roots are deformed into “L”, “S” or “J” shap (Fig. 10). Bad soil preparation and inadequate (small) planting tools cause bending and distorting of roots and put them shallow into dryer, warmer soil layer. Both container-type trees over 7 years of age have similar lateral root deformations. PP trees have more frequent deformations of vertical, i.e. tap root as consequence of primary and secondary deformations (Fig. 3). Because of secondary growth, spiralled and tangled roots get closer, strangulate and grow together, which results in some cases by stronger or poorer swelling at the zone of the former container (Fig. 8). Secondary deformations were registered in container and bare root tree types (Fig. 3, 11).

Indexes *R* (root collar: all roots), *HV* (horizontal: vertical roots) and *A* (asymmetry) complete the picture of root systems morphology and development deviations (Table 4).

Index *R* indicates whether the above ground part (represented by root collar diameter) of the tree is followed by appropriate root system, while index *HV* indicates ratio between horizontal and vertical roots. The larger the index *R* and *HV* is, the proportionally smaller root system tree develops, i.e. the smaller is the proportion of vertical roots in root system (Fig. 7). Both indexes in this investigation confirm that container trees develop root systems morphologically close to bare root trees. Index *A* reveals range of asymmetricity of horizontal root spreading. Larger index indicates bigger root eccentricity (index 1.0 means regular, even horizontal roots distribution). Analyzed trees of all types have mostly highly asymmetric root systems. However, in the time of investigation no signs of deterioration of stability of trees was recorded. Mann-Whitney’s test of differences (with one exception) confirms similarity of root parameters between all stock types.

Results of this investigation confirm conclusions of analyzes of different species of pines, exposed by Volná and Mauer (1983), Lindström and Rune (1999) on *P. sylvestris* L., Stilinović et al. (1986), Kolevska (1997) on *P. nigra* Arn., Plourde et al. on *P. banksiana* Lamb. (2009) etc. Kolevska (1997) analyzed morphometry and morphology of container and bare root *P. nigra* trees. She explored number, diameter, horizontal distribution and vertical stratigraphy of skeleton roots. Despite various stock types, root features of the trees show similarities. Root morphology is influenced by numerous factors (soil type and preparation, planting techniques etc.) Rune (2003) analyzed 6-year-old *P. sylvestris* trees from solidwall and slittwall containers, on fertile and poor site. Soil type (fertile-poor) affects root morphology (differences in CSA of horizontal and vertical roots). He did not found asymmetry between container types (using ratio between the quadrant with the largest CSA and the total CSA). Robert and Lindgren (2006) analyzed root features of container and natural trees of *P. contorta* Dougl. ex Loud. They established influence of container on occurrence of numerous root deformations (poor taproot, spiral roots, poor lateral spread, lateral compression etc.), but also deformations as consequence of poor planting. Plourde et al. (2009) analyzed 15-year-old natural and rigid wall containers trees of *P. banksiana*. Container trees display high frequency of deformities or total absence of vertical roots and irregularities in horizontal root distribution.

It is obvious from this investigation that older trees of both container types "manage" to overcome the initial root condition and develop functional root

Table 2. Root features and deformations and X^2 test, trees 4–5 years old.

Seedl. stock type	Age, years	N	Horizontal root spreading deviations, %			Deform. of lateral roots in shape, %		Trees, with typical tap root, %	Trees with-out vertic. roots, %	Deformations of tap root in shape, %			Roots knotting, %		
			unila-teral root syst.	bila-teral root syst.	absence of roots in 1/2 of radius	"elbow"	"ring"			"S"	"L"	"O"	poor	me-dium	strong
	4	30	10	10	20	75	75	90	10	30	40	0	10	50	20
PP	4	30	10	10	15	90	30	60	15	5	15	20	15	15	20
	5	30	50	20	10	90	60	85	0	15	20	10	20	30	5
	4	30	20	20	20	75	80	80	10	20	25	20	10	50	30
YS	4	11	10	10	5	70	90	82	0	10	10	0	30	40	0
	4	20	20	20	30	50	25	95	0	5	10	5	10	15	10
	5	30	5	10	5	75	65	83	7	5	5	10	5	20	30
BR	5	30	30	10	20	0	10	100	10	50	20	10	10	10	0
	5	11	0	0	0	60	80	73	9	0	10	10	20	40	10
X^2 test for root features and deformations, trees 4–5 years old (* – significance p<0.05)															
PP-YS			8.715*	0.033	0.030	5.982*	0.941	0.648	0.355	0.794	3.680	0.000	0.471	0.002	1.889
PP-BR			9.725*	0.499	0.015	54.483*	6.789*	2.911	0.027	5.251*	0.717	0.073	0.057	2.528	2.755
YS-BR			1.516	0.999	0.022	28.812*	12.133*	0.999	0.276	10.452*	0.102	0.008	0.008	2.063	6.671*

Table 3. Root features and deformations and X^2 test, trees 7–19 years old.

Seedl. stock type	Age, years	Rooting deviations, %			Spiralization of lateral roots, %			Trees with typical tap root, %	Trees without vert. roots, %	Deformations of tap root in shape, %			Root knotting, %			Swelling of former container zone, %		
		unilateral root syst.	bilateral root syst.	Absen. of roots in $^1/_2$ of radius	poor	medium	strong			"S"	"L"	"J"	poor	medium	strong	poor	medium	strong
PP	10	5	0	65	20	40	25	70	10	30	0	0	35	40	15	5	25	15
	10	30	5	50	25	25	0	70	5	5	10	5	30	10	15	0	0	5
	11	0	10	60	50	35	0	50	0	5	5	0	20	50	10	10	0	0
	12	3	13	43	43	37	20	27	3	20	7	0	20	50	0	33	0	7
	13	0	6	24	53	41	0	77	0	12	0	0	41	29	0	6	0	0
	13	0	16	32	42	47	0	95	0	11	0	16	42	21	5	5	0	0
	13	0	0	24	53	35	0	82	0	12	6	6	29	35	0	0	0	0
	14	20	0	10	50	35	0	65	0	5	5	35	20	50	0	0	0	0
YS	7	0	10	10	27	40	20	67	0	7	3	0	10	43	15	30	7	1
	8	15	10	40	30	45	20	65	0	10	0	0	25	60	5	30	5	0
	10	0	18	18	35	47	18	50	0	0	0	0	23	35	12	12	12	0
	11	0	0	7	53	33	0	53	0	0	0	0	53	37	0	0	0	0
	16	0	0	17	52	38	0	65	0	0	0	0	24	14	0	0	0	0
BR	9	0	0	20	33	23	0	80	3	13	0	0	27	27	7	20	3	0
	11	0	24	29	6	24	12	80	0	24	29	24	41	18	6	6	0	0
	12	0	11	33	33	22	0	65	0	33	11	6	39	17	6	0	0	0
	17	0	10	10	40	10	0	59	0	10	0	0	50	25	0	0	7	0
	19	0	10	10	33	7	0	73	0	0	0	0	33	17	0	3	0	0
X^2 test for root features and deformations, trees 7–19 years old (* – significance p<0.05)																		
PP-YS		0.960	0.172	11.96*	0.175	0.355	2.241	0.086	1.613	5.947*	2.096	7.985*	0.503	0.002	0.000	2.298	0.179	3.129
PP-BR		5.768*	0.300	8.254*	2.744	8.252*	1.821	0.931	0.102	0.834	0.587	0.156	2.353	4.548*	0.028	0.077	0.110	2.143
YS-BR		2.247	0.321	0.006	1.214	11.180*	6.684*	1.608	0.021	10.350*	5.013*	4.656*	4.743*	4.736*	0.145	2.830	0.058	0.001

systems, which are able to supply trees with water, nutrients and give them support. Such hstatement expose also Lindström and Rune (1999). Results of our investigation are in approval with Scagel (1995), who divides conifer root development into three phases: establishment, proliferation and maturation. Applied to our investigation, young trees (4–5 years of age) face proliferation phase which seems to be critical for survival and vitality, while older trees enter maturation phase and improvement of root morphology and overall tree development is obvious. Investigations of Kolevska and Trajkov (2012), who analyzed development of aboveground parts of container and bare root *P. nigra* trees, sup-

Table 4. Roots parameter indexes.

Seedling stock type	Age, years	N	Index R CSA of root collar/ CSA of all skeletal roots (horizontal+vertical)	Index HV CSA of horizontal skeletal roots/CSA of vertical skeletal roots	Index A CSA of roots of two quadrants with max. values/CSA of roots of two quadrants with min. values
PP	4	30	0,66	1,98	2,30
	4	30	0,98	2,10	3,90
	5	30	0,72	1,20	1,19
	10	20	0,74	0,82	5,77
	10	20	0,60	0,40	4,67
	11	20	0,55	2,10	2,75
	12	30	0,62	0,95	3,64
	13	17	0,71	1,01	3,35
	13	19	0,82	0,96	3,22
	13	17	0,76	1,09	2,95
	14	20	0,64	1,46	3,79
YS	4	30	0,5	1,2	2,7
	4	11	1,0	2,3	4,0
	4	20	0,6	2,6	4,3
	5	30	0,7	1,2	4,9
	7	30	0,5	1,3	3,4
	8	30	0,6	1,1	4,1
	10	20	0,6	1,4	2,5
	11	17	0,6	1,0	2,6
	16	30	0,6	1,0	3,9
BR	5	30	0,58	1,51	1,22
	5	11	0,82	0,86	1,59
	9	30	0,66	0,81	3,07
	11	17	0,54	1,24	2,77
	12	18	0,56	1,67	2,72
	17	30	0,65	1,61	2,73
	19	30	0,69	1,07	3,20

Mann-Whitney's *U* test (* – significance *p*<0.05)

seedling stock types	*U*	*p*	*U*	*p*	*U*	*p*
PP-YS	23.500	0.046*	36.000	0.331	41.500	0.552
PP-BR	25.000	0.246	38.000	1.000	17.000	0.056
YS-BR	28.000	0.758	28.000	0.758	15.000	0.091

port this statement. Young trees of all stock types have more or less the same height and diameter but vitality of trees is poor to medium. Older trees develop well and their vitality is good. Influence of primal container is restrained.

1. PP 1+0

2. PP 4-years

3. PP 10-years

4. PP 14-years

Fig. 1–4. PAPERPOT seedlings and trees: “Elbow” deformations of lateral roots, L-curved tap root, eccentrical root system (1); knotted and twisted lateral and vertical roots (2); one half of rooting radius without roots, absence of vertical roots, swelling at the zone of former container (3); unilateral root system (4).

5. YS 1+0

6. YS 4-years

7. YS 11-years

8. YS 16-years

Fig. 5–8. YUCOSAD seedlings and trees: "Elbow" deformations and knotting of lateral roots, (5); knotting and twisting of lateral roots (6); poorly developed vertical roots (7); swelling of the zone of former container due to ingrown roots (8).

9. BR 1+0

10. BR 5-years

11. BR 11-years

12. BR 11-years

Fig. 9–11. BARE ROOT seedlings and trees: typical root morphology (9); unilateral root system, vertical roots deformation (10); spiralling of lateral roots, (11), bilateral root system, "L" shape of vertical roots (12).

Conclusions

Root systems of seedlings of both container types are modified and deformed by the container (primary deformations). Morphology and deformations of root systems of young trees of both container types are similar and the influence of primal container is still perceptible. Root systems of older trees gradually overcome this disposition and develop according to site conditions ensuring functionality and stability. Secondary deformations take part in root morphology modification of all seedling stock types.

There is no significant difference between Paperpot and Yucosad seedlings and trees features, roots morphology and field performance. Deformations of roots are quite often in container-type stands. However, all container and bare root seedling type trees' growth and vitality depend mostly on site conditions and planting technique.

References

Dominguez-Lerena S., Herrero Sierra N., Carrasco Manzano I., Ocaña Bueno L., Peñuelas Rubira J.L., Mexal J.G. 2006. Container characteristics influence *Pinus pinea* seedling development in the nursery and field. Forest Ecology and Management, Volume 221, issues 1–3: 63–71.

Girouard R.M. 1991. Container type affects development of Jack Pine seedlings three years after outplanting. "Root ecology and its practical application". Abstracts, 3rd International Society of Root Research Symposium, September 2–6, 1991, Vienna.

Kolevska D. 1995. Influence of seedling type and soil conditions on root development of Black Pine (*Pinus nigra* Arn.) in Macedonia. Doctoral dissertation, Skopje, 305 p. (in Macedonian).

Kolevska D. 1997. Influence of seedling type on root development on Black pine (*Pinus nigra* Arn.) in Macedonia. The 3rd International Conference on the Development of Forestry and Wood Science/Technology. Belgrade. Volume I: 129–137.

Kolevska D.D., Trajkov P. 2012. Quality and development of containerized seedlings and stands of Austrian pine (*Pinus nigra* Arn.) in the Republic of Macedonia. Forestry Ideas, vol. 18(1): 19–27.

Lindström A., Rune G. 1999. Root deformation in plantations of container-grown Scots pine trees: effects on root growth, tree stability and stem straightness. Plant and Soil, Volume 217, No 1–2: 29–37.

Lokvenc T. 1980. Typification of Root Deformations in Cultures Established with Containerized Plant Stock. Praha. Forestry 26 (2): 109–118 (in Czech).

Plourde A., Krause C., Lord D. 2009. Spatial distribution, architecture, and development of the root system of *Pinus banksiana* Lamb. in natural and planted stands. Forest Ecology and management, Volume 258, Issue 9: 2143–2152.

Popovski P. 1985. Deformation of root system of seedlings produced in containers Kopparfors and Yucosad in Macedonia. Conference: Development of Forest Stands in SR Serbia raised by Seedlings produced in Hard Plastic Containers, Book of Papers, Belgrade, Institut za šumarstvo i drvnu industriju: 1–7 (in Macedonian).

Scagel R. 1995. Root growth characteristics of conifers in Northern Boreal Forests. Management of Slow-Growing Northern Boreal Forests Field Conference, Natural Resources Canada, Canadian Forest Service Northwest Region: 1–7.

Stilinović S., Georgievic D., Markovski K., Grbic M. 1980. Contribution to the better knowledge of forest seedlings root form and configuration raised by different nursery growing techniques. Belgrade, Bulletin of College of Forestry 54: 203–215 (in Serbian).

Stilinović S., Georgievic D., Vlainic A. 1986. Degree of Endangering of Black Pine Plantations depending on the type of Root

Deformation intensity. Belgrade, Forestry 5–6: 9–27 (in Serbian).

Robert J.A., Lindgren B.S. 2006. Relationship between root form and growth, stability and planted versus naturally regenerated lodgpole pine in north-central British Columbia. Canadian Journal of Forest Research 36: 2642–2653.

Rune G. 2003. Slits in Container Wall Improve Root Structure and Stem Straightness of Outplanted Scots Pine Seedlings. Research Articles, Silva Fennica 37 (3): 333–342.

Volná M., Mauer O. 1983. Development of the root system in Scot Pine (*Pinus sylvestris* L.) in cultures established using seedlings of the KOPPARFORS and PAPERPOT types. Brno, Acta Universitatis Agriculturae 52: 291–308 (in Czech).