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ORIGINAL ARTICLES

Effect of Polymers on Scots Pine (*Pinus Silvestris* L.) And Austrian Pine (*Pinus Nigra* Arn.) Seedling Development In Afforestation

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Introduction

The increase in forest cover percentage is one of the strategic goals in many countries. The realisation of such an ambitious plan is all the more difficult under the climate changes which appreciably reduce the planting season and negative impact on plant survival and development, due to long, hot and dry summers. Also, the uncovered areas intended for re/afforestation are mainly difficult terrains, damaged by wildfires, or degraded in other ways. Such soils, without the humus horizon, most often of south and southeast aspect, ecologically unfavourable because of strong insolation and the lack of moisture, without forest cover and with forest mycoflora completely missing, require the application of modern re/afforestation technologies combined with the latest scientific knowledge.

During the eighties of the twentieth century, to intensify the agricultural production, the American scientists developed the substance called *Super Absorbent Polymer* based on polymers (non toxic acrylamide), today known under different names (superabsorbent, hydrogel, water-absorbing crystals), and trade names (Horta-Sorb®, Super-Hydro-Grow, etc.), depending on the type and the manufacturer. The first polymer formulations were based on inorganic substances. However, because of the residual substances which remain in the soil after their decomposition, it is the organic polymers that are increasingly used nowadays.

The positive experience refers to the application of polymers: as an addition to soil mixtures for plant production and cultivation (Henderson & Hensley, 1986; Kjelgren *et al*., 1994; Kahl *et al*., 2000; Vilotić *et al.,* 2006; Kresović *et al*., 2008; Dragičević *et al*., 2008), stimulators of seed germination (Henderson & Hensley, 1987, 1987a), for immersing the bare-root seedlings in long transport, for soil stabilisation (Aly & Letey 1989, 1990; El-Hady *et al*., 1981, 1991; Barvenik, 1994; Bouranius *et al*., 1995; Mikkelsen R.L., 1994), for the stimulation of plant survival and growth in the establishment of tree rows, shelterbelts, and in the reforestation of difficult and degraded terrains in climatically modified environmental conditions (Cook & Nelson, 1986; Callaghan *et al.,* 1989; Huttermann *et al*., 1997, 1999; Vilotić & Šijačić-Nikolić, 2008, 2009; Višnjić *et al*., 2003, 2004; Šijačić-Nikolić *et al.,* 2008).

Material and method

To analyse the superabsorbent polymer effect on the development of Scots pine and Austrian pine seedlings in the first years after afforestation, two experiments were established in the spring 2008. The first experiment was established on the burnt area of the Sands Deliblatska Peščara, with Scots pine seedlings (*Pinus silvestris* L.) aged 2+1, produced in Nisula rolls, Figure 1. The second experiment was established at the locality Kremin, with containerised seedlings of Austrian pine (*Pinus nigra* Arn.), aged 2+0, Figure 2. The

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seedlings were planted in holes, with 2.5 m distance between the rows and 1.5 m spacing between the seedlings. The rows were recorded and monitored as the control (K) and the treatments (T1, T2 and T3), in three replicates, Table 1.

Table 1: Description of the control and treatments in the experiments

Description	Treatment	Experiment 1 Deliblatska Peščara	Experiment Kremin
Seedlings planted in holes without added polymers	Control	K	K
Seedlings planted in holes with added 2.5 g of polymer	Treatment 1	T1	T1
Seedlings planted in holes with added 5 g of polymer	Treatment 2	T2	T2
Before planting, seedling roots were soaked in polymer gel-solution in water	Treatment 3	T3	

The following polymers were tested: *Water Retainer/Polymers - Hydro Absorption Rate between 250 and 350* (Manufacturer Super Absorbent Company, 10 Chrysler, Suite B, Irvine, CA 92618, Website: www.SuperAbsorbent.com), in powder state. The basic characteristics of these polymers are organic origin, ability of absorbing and retaining water more than 300 times their own weight, inactivity from the chemical aspect, neutral pH value, capacity of remaining in the soil up to three years, and capacity of decomposition into organic elements available to plants.

а б

Fig. 1: The experiments on Deliblatska Peščara: **(a)** the site; **(b)** Scots pine seedlings, aged 2+1, produced in Nisula rolls

a b

Fig. 2: The experiments at Kremin: **(a)** the site; **(b)** containerised Austrian pine seedlings, aged 2+0

Taking into account that the polymer activity and implementation largely depend on climate conditions, they are presented based on the reports of the nearest meteorological stations for 2008, Tables 2 and 3.

Table 2: Air temperature and precipitation recorded by meteorological station Bela Crkva (latitude 44º 54`, longitude 21º 25`, altitude 90 m), as the nearest to experiment 1. http://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_godisnjaci.php

Month	Air temperature (º C)			Precipitation (mm)	
	Mean value	Maximum value	Minimum value	Mean value	Maximum value
1	1.3	14.2	-	28.5	12.2
2	4.3	21.2	-	11.4	7.0
3	8.5	19.2	-	91.6	23.5
4	13.1	24.7	-	56.0	18.0
5	18.1	33.7	-	49.7	33.6
6	21.7	35.2	10.4	70.1	55.0
7	22.1	33.7	10.6	38.7	17.4
8	23.1	36.4	7.5	51.4	24.5
9	16.2	35.8	3.0	55.1	20.0
10	13.4	24.2	3.0	41.6	23.5
11	8.5	23.0	-4.0	42.7	28.5
12	3.9	15.4	-11.0	56.5	8.5
year	12.9	36.4	-	593.3	55.0

Table 3: Air temperature and precipitation recorded by meteorological station Kraljevo (latitude 43º 43`, longitude 20º 42`, altitude 215 m) which is the nearest to experiment 2. http://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_godisnjaci.php

Month	Air temperature (º C)			Precipitation (mm)	
	Mean value	Maximum value	Minimum value	Mean value	Maximum value
1	1.6	14.4	-14.5	32.6	10.7
2	4.5	23.4	-9.5	22.1	13.4
3	8.0	21.8	-1.8	72.4	16.1
4	12.4	26.2	0.6	62.9	24.6
5	17.2	34.6	4.6	40.1	10.7
6	21.2	34.8	10.7	73.4	21.7
7	21.6	36.6	11.5	153.0	54.1
8	22.2	35.9	9.9	57.1	47.2
9	15.2	34.9	4.0	72.3	26.0
10	12.8	24.5	2.4	39.8	21.3
11	8.0	28.2	-8.0	48.2	24.8
12	4.4	18.6	-8.5	41.1	9.7
year	11.5	36.6	-14.5	715.0	54.1

In the autumn 2008, on the sample of 30 plants, total seedling height (cm) and height increment (cm) were analysed in the control and three different treatments over the first year after transplanting. In the autumn 2009, total seedling height (cm) and height increment (cm) were recorded on the same sample after the second year, and also the root collar diameter (mm). The collected data were processed using computer programme «Statgraph 6.0».

Results and discussion

The results are presented separately for experiment 1 and experiment 2. The summary statistics, analysis of variance and LSD test for morphometric parameters of Scots pine seedlings in treatments (T1, T2 and T3) and control (K), in experiment 1, are presented in Table 4.

Based on the study results, it can be concluded that the differences between mean values of seedling height and height increment in 2008, in the control and treatments T1, T2 and T3, are not statistically significant. The significant differences between mean values of the above morphometric parameters were observed in 2009, i.e. the maximal values were attained by the seedlings in treatment T2, and the minimal - in treatment T3, Diagram 1. The same was observed also for root collar diameter, Figure 1.

Table 4: Summary statistics, analysis of variance and LSD test for Scots pine seedling morphometric characters in 2008 and 2009, experiment 1

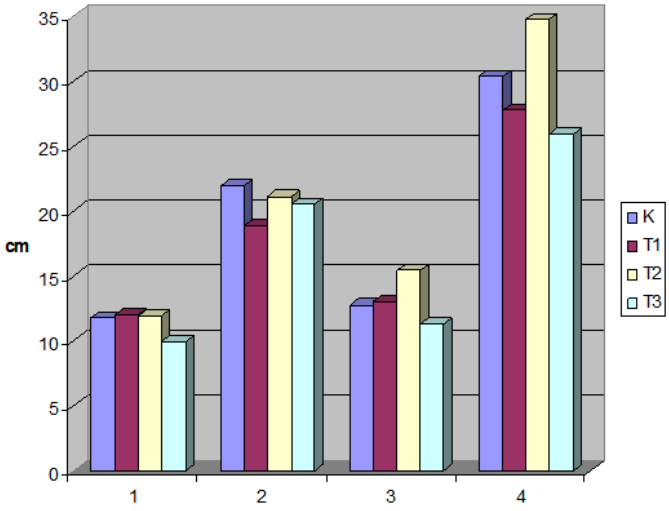
	Min	Max	Average	Standard deviation
		Seedling height in 2008 (cm)		
K	10.00	36.00	21.92	6.47
T1	7.00	34.00	18.88	6.82
T2	11.00	37.00	21.08	7.37
T3	9.00	33.00	20.52	6.23
Analysis of Variance				
Between control and tretmans		F-Ratio	P-Value	
		0.91	0.4413	
LSD Test				

Table 4: Continue

	Average	Homogeneous Groups		
T1	18.88	X		
T3	20.52	X		
T2	21.08	X		
K	21.92	X		
		Seedling height increment in 2008 (cm)		
K	4.00	20.00	11.76	4.69
T1	5.00	20.00	12.04	3.32
T2	7.00	19.00	11.92	3.88
T3	5.00	16.00	11.00	2.76
Analysis of Variance				
Between control and tretmans		F-Ratio	P-Value	
		1.72	0.1675	
LSD Test				
	Average	Homogeneous Groups		
T3	9.96	X		
K	11.76	X		
T2	11.92	X		
T1	12.04	X		
		Seedling height in 2009 (cm)		
K	9.00	53.00	30.32	10.68
T1	15.00	48.00	27.72	9.23
T2	18.00	56.00	34.72	10.54
T3	8.00	48.00	25.92	10.67
Analysis of Variance				
Between control and tretmans		F-Ratio	P-Value	
		3.44	0.0199	
LSD Test				
	Average	Homogeneous Groups		
T3	25.92	X		
T1	27.72	X		
K	30.32	XX		
T2	34.72	X		
		Seedling height increment in 2009 (cm)		
K	2.00	26.00	12.76	6.03
T1	7.00	23.00	13.04	3.85
T2	5.00	23.00	15.40	3.97
T3	2.00	25.00	11.28	5.74
Analysis of Variance				
Between control and tretmans		F-Ratio	P-Value	
		2.91	0.0385	
LSD Test				
	Average	Homogeneous Groups		
T3	11.28	X		
K	12.76	XX		
T1	13.04	XX		
T2	15.40	X		
		Root collar diameter in 2009 (mm)		
K	2.34	15.40	8.24	2.52
T1	3.31	13.72	7.61	2.57
T2	4.71	13.71	8.88	2.25
T3	3.20	9.42	6.52	2.08
Analysis of Variance				
Between control and tretmans		F-Ratio	P-Value	
		4.52	0.0052	
LSD Test				
	Average	Homogeneous Groups		
T3	6.52	X		
T1	7.60	XX		
K	8.24	X		
T2	8.88	X		

The summary statistics, analysis of variance and LSD test for morphometric parameters of Scots pine seedlings in the treatments (T1 and T2) and the control (K), in experiment 2, are presented in Table 5.

Based on the study results, it can be concluded that in 2008 the highest values of height and height increment were attained by the seedlings in treatment T2, when the differences between the mean values were statistically significant only for height increment. During 2009, the calculated differences between the mean values were statistically significant for seedling height and height increment, and the highest values were also recorded in treatment T2, Diagram 2. The differences between the mean values of root collar diameter were the highest in treatment T2, although they were not statistically significant.



1. seedling height increment in 2008; **2.** seedling height in 2008; **3.** seedling height increment in 2009; **4.** seedling height in 2009

Diagram 1: Variability of Scots pine seedling height and height increment over 2008. and 2009 in the control (K) and treatments (T1, T2 and T3), experiment 1

Fig. 1: Scots pine seedling (treatment T2) and its root, experiment 1, autumn 2009

Table 5: Summary statistics, analysis of variance and LSD test for Scots pine seedling morphometric characters in 2008 and 2009, experiment 2

	Min	Max	Average	Standard deviation
		Seedling height in 2008 (cm)		
K	7.1	33.0	16.33	5.00
T1	9.0	24.2	15.20	4.41
T2	10.6	30.0	17.81	4.35
Analysis of Variance				
Between control and tretmans		F-Ratio	P-Value	
		1.41	0.25	
LSD Test				
	Average	Homogeneous Groups		
T1	15.90	X		
K	16.35	X		
T2	17.81	X		

Table 5: Continue

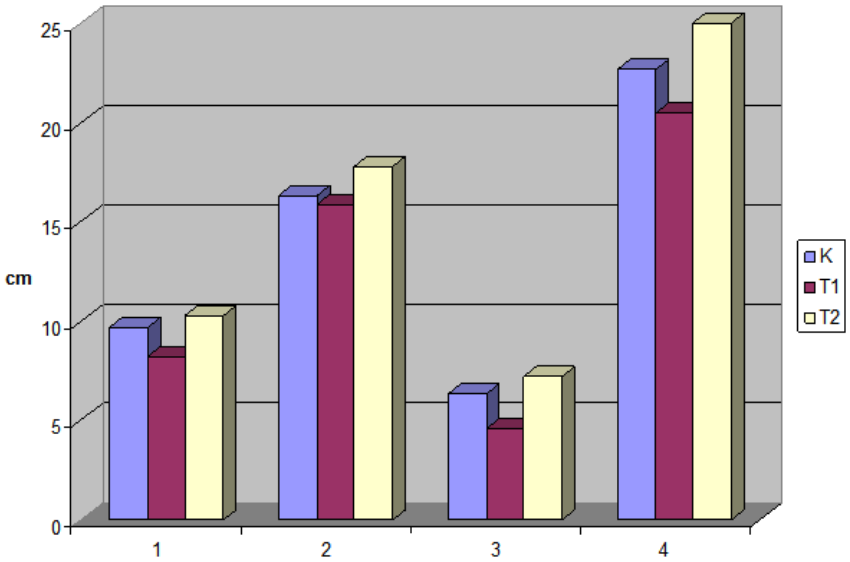
		Seedling height increment in 2008 (cm)		
K	3.60	23.50	9.72	4.20
T1	2.50	16.60	8.26	3.44
T2	3.40	20.60	10.29	3.79
Analysis of Variance				
Between control and tretmans		F-Ratio	P-Value	
		2.23	0.11	
LSD Test				
	Average	Homogeneous Groups		
T1	8.26	X		
K	9.72	XX		
T2	10.29	X		
		Seedling height in 2009 (cm)		
K	13.00	41.00	22.66	6.24
T1	11.00	31.00	20.00	5.78
T2	13.00	41.00	25.00	6.02
Analysis of Variance				
Between control and tretmans		F-Ratio	P-Value	
		4.19	0.0183	
LSD Test				
	Average	Homogeneous Groups		
T1	20.50	X		
K	22.67	XX		
T2	25.00	X		
		Seedling height increment in 2009 (cm)		
K	0.80	13.00	6.31	2.82
T1	0.50	10.00	4.60	2.79
T2	0.50	12.90	7.19	3.26
Analysis of Variance				
Between control and tretmans		F-Ratio	P-Value	
		5.90	0.0039	
LSD Test				
	Average	Homogeneous Groups		
T1	4.60	X		
K	6.31	X		
T2	7.19	X		
		Root collar diameter in 2009 (mm)		
K	4.97	18.92	8.15	2.98
T1	4.67	11.62	7.58	2.06
T2	5.11	13.36	8.62	2.31
Analysis of Variance				
Between control and tretmans		F-Ratio	P-Value	
		1.32	0.2721	
LSD Test				
	Average	Homogeneous Groups		
T1	7.58	X		
K	8.15	X		
T2	8.62	X		

Conclusion

The experiments on the effect of *Water Retainer/Polymers - Hydro Absorption Rate between 250 and 350* on Scots pine and Austrian pine seedling development in the first two years after afforestation, show the following results:

- positive effect of polymers on height, height increment and diameter of Scots pine and Austrian pine seedlings;
- cumulative effect of polymers whose effect is intensified during the second year after the afforestation;
- the highest values of the analysed morphometric characters of Scots pine and Austrian pine seedlings in treatment T2, with 5 g polymer added to planting holes;
- the lowest values of the analysed morphometric characters of Scots pine seedlings in treatment T3, when seedling roots were soaked in polymer gel-solution in water before planting;
- justification of their use in afforestation of degraded sites in climate conditions characterised by lower precipitation and higher average temperatures.

The functional principle of polymers is especially significant if we take into account the climate at the study localities, i.e. the annual precipitation considerably lower than normal in Serbia, which is 896 mm, and the average annual air temperature above 10.9ºC, which is the average value for the altitudes up to 300m



1. seedling height increment in 2008; **2.** seedling height in 2008; **3.** seedling height increment in 2009; **4.** seedling height in 2009

Diagram 2: Variability of height and height increment of Austrian pine seedlings over 2008. and 2009 in the control and treatments (T1 and T2), experiment 2

(http://www.hidmet.gov.rs/ciril/meteorologija/klimatologija_temp_rezim.php). Polymers absorb water when water is available, they retain it and release to the plant when it is absent in the environment. In this way, moisture is permanently available to the plant, regardless of the periodicity of atmospheric precipitation, which has a positive effect on plant development.

The study results show that polymer application is economically justified thanks to the higher seedling survival (Šijačić-Nikolić *et al.,* 2008) and their better and more intensive growth over the first years after afforestation. Based on the study results, the amount of 5 grams of powder polymer per planting hole can be recommended for the re/afforestation with Scots pine and Austrian pine seedlings.

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