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Effects of planting interval and soil type on volume production and slenderness index of poplar (*Populus nigra* L.) plantations in Diwandareh region (Kurdistan province, western Iran)

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Abstract

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Tests were done on seven poplar (*Populus nigra* Linnaeus) plantations to investigate the effects of planting interval of stands and soil properties on total volume production, commercial volume production and slenderness index. The parameters of stands like diameter at breast height, total height, stem height, total volume, commercial volume and slenderness index were measured and compared with soil characteristics and planting intervals. Results showed significant differences in qualitative characteristics of poplar stands in relation to tested planting intervals and physical soil characteristics. The highest mean commercial volume was found at planting interval of 2 × 2 m and at slenderness index mean near one. Characteristics of poplar stands showed the strongest correlation with physical properties of soil rather than with chemical ones. Soil properties had a higher effect on quantitative characteristics of the studied poplar stands in comparison with planting interval.

Keywords: poplar cultivation; stand; physical properties; chemical properties; growth

Destruction of natural forests, increasing human population and slow growth of most broadleaf forest species mean that the wood requirements (for quantity and quality) of various industries in Iran are not currently being met. This problem determines the importance of afforestation with fast-growing and native species, including *Populus nigra* Linnaeus (Pourbabaei et al. 2004). In afforestation systems, it would be economical to solve problems prior to starting the afforestation program. One of the problems in large plantations is to maintain uniform distances between trees (Radcliffe et al. 1981), because plants growing at different distances differ in terms of qualitative and quantitative characteristics, and the most suitable planting distance must be determined for a better result. It is important to determine proper patterns for plant spacing in order to reduce weeds and maximize performance (Baki et al. 1995; Murphy et al. 1996; Knezevic et al. 2003). In this vein, Riahifar et al. (2008) observed the maximum height and diameter growth for two species: *Populus deltoides* Bartram ex Marshall and *Paulownia fortunei* (Seemann) Hemsley at the spacing of 3 × 3 m. Research has shown that the soil is an important source of nutrients such as nitrogen, phosphorus, sulphur, sodium, magnesium, calcium as well as several micronutrients that are required by vegetation (Donegan et al. 2001; Lal 2005). In some cases, soil characteristics such as pH and available nutrients influence vegetation. Soil nutrients can affect conditions of vegetation and species distribution in areas with slopes and height variations (Wenqiang et al. 2010). If the other conditions are fixed, this can be removed (in some cases). It has been reported that poplar has the best growth in deep soil with medium texture (loamy texture) (Schreiner 1959) and on light sandy soil (Woods, Hanover 1982). Kiadeliri et al. (2004) concluded that grey-brown podzolic and brownish forest soils with high organic matter were the most suitable soil types for cultivation and development of poplar forests. Therefore, the present study tried to investigate these two factors and answer the question whether or not soil type and planting interval had any effect on the quantitative characteristics of trees in poplar plantations.

MATERIAL AND METHODS

Research was conducted in the Diwandareh region in the Kurdistan province. Seven poplar plantation stands were studied in this research. One of the stands was in the village of Zaghe-Sofla, two stands were in the village of Taze-Abad and four stands were located in the village of Gharedarre near the city of Diwandareh. Basic characteristics of the poplar stands are presented in Table 1. The plantations selected for the study had been planted by villagers in different plantation intervals of 2 × 2 or 1 × 1 m, so it was not possible to find two stands with equal plant spacing and design.

According to statistics of the Zarrineh synoptic meteorological station (2001–2011), maximum and minimum temperatures in the region were 36.5 and –23°C, respectively, and there were 272 dry days and 140 days of frost. The average annual rainfall was 350–450 mm (Majidi 2010). There were five dry months; June, July, August, September and October, and the average annual relative humidity was 54% (Anonymous 2011). There was only one climate station in the study area, so poplar stands that were in close proximity to each other were selected so that differences in climate data between the stands could be ignored. A transect sampling method was used for sampling with 10% intensity. In each row, the first tree is randomly selected and the next trees are selected systematically as the tenth, twentieth, thirtieth, etc. in order. For each stand geographical coordinates, altitude, stand area, slope, and DBH were determined. Measurements of geographical coordinates, altitude and area were taken with GPS; evaluations for slope and height of trees were made with PM-5/360 PC clinometers (Suunto, Finland); DBH was measured with a Vernier calliper (MET821; Harden Tools Co., China) and all values were recorded on data collection sheets. The slenderness coefficient (indicator of tree stability) was calculated as the ratio between tree height (m) and DBH (cm). Using the information gathered on data sheets evaluations for total height, stem height (trunk height without branches), total volume and commercial volume were calculated by the simple formula of volume (Zobeyri 2005).

The soil status was determined for each stand by taking three soil samples, a total of 21 samples. Soil samples were taken from pits that were dug (40 × 40 cm^2 in size and 0–30 cm in depth) in each stand and approximately one kilogram of soil was taken as a sample and transferred to the agrological laboratory. In each of the 7 poplar plantations of rectangular form, we selected three pits along each side of the rectangular with a size of 40 × 40 cm and depth of 30 cm. The soil sample of each pit was thoroughly mixed from surface to depth of 30 cm. The following soil characteristics were determined: texture with hydrometer, bulk density by clod method, carbonate content by titration method, pH (in distilled water using a 1:2.5 soil/water ratio), organic carbon content by Walkley-Black method (Allison 1975), total nitrogen by Kjeldahl method (Bremner, Mulvaney 1982), plant available phosphorous according to the standard methods – Olsen P (Olsen et al. 1954), plant

Table 1. General properties of the studied poplar stands

Stand	Name	Area (m^2)	Planting interval (m)	Altitude (m a.s.l.)	Slope (%)	Aspect	Latitude	Longitude	Year of planting	Texture of soil
1	Kani Sheykh	1,800	1 × 1	1,380	5	north	35°45'9"N	47°5'32"E	2006	silty clay loam
2	Taze-Abad No. 2	1,500	1 × 1	1,330	4	north	36°6'8"N	47°6'0"E	2006	clay loam
3	Bishe Mohammadi	2,320	2 × 2	1,440	2	north	36°6'5"N	47°5'3"E	2006	sandy loam
4	Bishe Ola	3,020	2 × 2	1,200	5	west	36°6'6"N	47°5'9"E	2006	sandy loam
5	Bishe Hasani	3,000	2 × 2	1,320	3	west	36°6'7"N	47°5'0"E	2006	sandy loam
6	Bishe Fattahi	1,740	2 × 2	1,270	3	east	36°6'5"N	47°5'5"E	2006	sandy loam
7	Taze-Abad No. 1	3,400	2 × 2	1,540	0	–	36°6'11"N	47°6'9"E	2006	sandy clay loam

available potassium by normal ammonium acetate extraction method and using a flame photometer soil porosity percentage by this formula (amount of water added to sample/total sample volume × 100) and C/N ratio by the ratio of organic carbon to total nitrogen. Quantitative and qualitative characteristics of stands and physiographic characteristics (aspect, slope and altitude) were recorded for analysis. Information on physical and chemical properties of the soil samples were recorded as a separate file. Recorded data were then entered into the computer using SPSS software (Version 18, 2012) for data analysis. Having controlled normality of the data, the one-way ANOVA test was employed for continuous data. The significance of differences between mean values of the stand characteristics was determined by means of Duncan's test.

RESULTS AND DISCUSSION

Based on ANOVA and results of Duncan's test, significant differences were determined between the mean total volumes, commercial volume and slenderness index values of the studied stands at a 5% level (Table 2).

Based on results of ANOVA and Duncan's test, there was a significant difference at a 5% level between the studied soil factors in case of mean saturation, total neutralizing value (TNV), organic carbon, available potassium, sand, silt, clay content percentage, bulk density, porosity and total nitrogen content (Table 3). In stand No. 1, TNV, organic carbon and total nitrogen contents were significantly higher. Stands No. 1 and 2 had the highest saturation and clay percentages and stands No. 3 and 4 had significantly higher amounts of sand (Table 3).

Table 4 shows a positive correlation between total volume production of poplar stands and soil saturation, pH value, content of organic carbon, available potassium, silt and clay, total nitrogen and C/N ratio. The commercial volume positively correlated with soil saturation, electrical conductivity, pH value, content of silt and bulk density of soil. A positive correlation was also found between plant available potassium and soil saturation, content of organic carbon, available potassium, silt, clay, total nitrogen and C/N ratio. On the other hand, the highest negative correlation was found between the total volume of poplar stands and plant available potassium and sand percentage, and between the commercial volume of poplar stands and soil porosity percentage.

The highest total volume production was observed in poplar stands No. 1 and 2, while the lowest total volume production was observed in stands No. 3 and 4 (Table 2). Since stands No. 1 and 2 had the 1 × 1 m planting interval, and stands No. 3 and 4 had the interval 2 × 2 m, it can be concluded that decreasing the planting interval was effective for increasing the total volume production of poplar stands. Similarly, the findings of this study are in agreement with research results reported by Khan and Chaudhry (2007) that an increase in planting distance decreased the volume production of *P. deltoides* plantations. Riahifar et al. (2008) observed the greatest height increment at smaller planting distance and Burgess et al. (2004) concluded that trees with larger planting distance (10 × 6 m) had lower height (9.5 m). Regarding soil properties, the positive correlation between total volume production and soil saturation, content of soil silt, clay, organic carbon, available potassium and total nitrogen, and the negative correlation between total volume production of poplar stands and content of sand, it can be concluded that the greatest total volume production occurred in soil with 30–40% saturation, silt content of 25–35%, clay content of 20–30% and sand content of 30 to 50% (loam texture) (Table 4). The higher level of mean organic carbon percentage, of the content of total nitrogen and available potassium resulted in the higher mean total volume production of poplar plantation. Moreover, it can be understood that regarding the total volume production, soil properties were more influential than planting interval. According to Hemmati and Modir-Rahmati (1999), pop-

Table 2. Quantitative characteristics of the studied poplar plantations (mean value)

Stand characteristic	Stand No.						
	1	2	3	4	5	6	7
Total volume (m^3)	0.094^a	0.085^a	0.029^c	0.024^c	0.067^b	0.063^b	0.086^a
Commercial volume (m^3)	0.03^b	0.02^c	0.10^d	0.10^d	0.03^b	0.03^{ab}	0.04^a
Slenderness index	1.12^b	1.31^a	0.73^d	0.68^e	0.91^c	1.06^b	1.04^b

Different letters indicate significant differences between individual mean values

Table 3. Mean values of soil factors in the studied poplar stands

Soil factor		Stand No.						
		1	2	3	4	5	6	7
Saturation (%)	mean	43.33[a]	45.00[a]	20.67[c]	22.00[c]	33.33[b]	34.00[b]	35.33[b]
	SE	2.67	3.00	1.20	1.00	3.48	2.51	2.60
Electrical conductivity (dS)	mean	0.77	0.60	0.71	0.56	0.88	0.67	0.67
	SE	0.07	0.03	0.02	0.12	0.06	0.06	0.04
pH-H_2O	mean	8.04	7.82	7.87	7.60	7.90	7.95	8.04
	SE	0.04	0.03	0.06	0.15	0.12	0.11	0.10
TNV (%)	mean	26.20[a]	15.83[bc]	11.64[c]	18.47[b]	14.63[bc]	19.53[b]	17.23[bc]
	SE	1.76	1.12	1.18	3.56	1.08	1.29	0.63
Organic carbon (%)	mean	2.05[a]	1.15[bc]	0.89[bc]	0.62[c]	1.32[b]	1.08[bc]	0.91[bc]
	SE	0.23	0.12	0.08	0.23	0.24	0.06	0.12
Available P ($mg \cdot kg^{-1}$)	mean	5.97	2.18	4.63	5.40	6.78	5.17	2.37
	SE	3.70	0.23	0.92	1.50	1.60	2.70	0.16
Available K ($mg \cdot kg^{-1}$)	mean	334.00[ab]	356.00[a]	147.67[c]	121.33[c]	199.00[c]	144.33[c]	169.00[c]
	SE	12.18	125.00	4.09	7.47	18.82	9.52	3.00
Sand (%)	mean	30.33[c]	37.00[c]	74.33[a]	80.00[a]	52.67[b]	54.33[b]	52.33[b]
	SE	6.00	4.60	2.60	3.60	5.20	3.33	3.28
Silt (%)	mean	37.00[a]	32.67[a]	13.00[b]	8.33[b]	28.33[a]	26.33[a]	26.67[a]
	SE	3.60	2.33	1.70	1.80	6.43	2.90	2.60
Clay (%)	mean	32.67[a]	30.33[a]	12.67[c]	11.67[c]	19.00[b]	19.33[b]	21.00[b]
	SE	2.40	1.85	0.88	1.76	2.60	1.33	1.00
Bulk density ($g \cdot cm^{-3}$)	mean	1.41[cd]	1.45[bc]	1.39[d]	1.48[abc]	1.46[cd]	1.55[a]	1.51[ab]
	SE	0.01	0.02	0.02	0.01	0.01	0.01	0.02
Porosity (%)	mean	43.92[ab]	41.93[bc]	46.94[a]	42.16[bc]	42.41[bc]	38.36[c]	40.48[bc]
	SE	1.34	1.04	0.05	1.19	1.50	1.42	0.24
Total nitrogen (%)	mean	0.20[a]	0.11[b]	0.09[b]	0.07[b]	0.13[b]	0.11[b]	0.09[b]
	SE	0.02	0.01	0.01	0.03	0.02	0.01	0.01
C/N ratio	mean	10.44	10.18	9.58	9.90	10.22	9.85	9.77
	SE	0.27	0.47	0.34	0.70	0.47	0.99	0.19

TNV – total neutralizing value, SE – standard error, different letters indicate significant differences between individual mean values

Table 4. Pearson's correlations between average chemical and physical properties of soil and poplar stand characteristics

Soil factor	Total volume production	Commercial volume production	Slenderness index
Saturation	0.904**	0.489**	0.967**
Electrical conductivity	0.056	0.387*	–0.273
pH-H_2O	0.592**	0.830**	0.215
TNV	0.174	0.170	0.111
Organic carbon	0.529**	0.303	0.444*
Available P	–0.574**	–0.214	–0.653**
Available K	0.617**	0.000	0.816**
Sand	–0.911**	–0.513**	–0.934**
Silt	0.924**	0.651**	0.877**
Clay	0.837**	0.311	0.943**
Porosity	–0.329	–0.597**	–0.318
Particle density	–0.725**	–0.451*	–0.876**
Bulk density	0.144	0.553**	0.073
C/N ratio	0.376*	0.010	0.444*
Total nitrogen	0.502**	0.310	0.421*

TNV – total neutralizing value, **significant at $\alpha = 0.01$, *significant at $\alpha = 0.05$

lar growth is influenced by chemical factors such as active nitrogen percentage of soil. Kiadeliri et al. (2004) concluded that grey-brown podzolic and brownish forest soils with high content of organic matter were the most appropriate for cultivation and development of poplar forests.

These findings are consistent with those reported by Schreiner (1959) that the best growth of poplar is in deep soil with medium texture. Pedlar et al. (2006) and Rezayi (2011) found higher volume production in loam soil with good drainage.

However, this study is in contradiction with that of Woods and Hanover (1982) that the best growth of Carolina poplar is in light, loamy sand soil.

Table 2 indicates the lowest slenderness index with a mean of less than one in stands No. 3 and 4 unsuitable for determination of height and diameter. Regarding soil properties and the positive correlation between the total volume production of poplar and saturation of soil by cations, contents of silt, clay, organic carbon, available potassium and total nitrogen, and the negative correlation between total volume production and percentage of sand, it can be concluded that the slenderness index mean of less than one occurred in soils with 20% saturation, content of 10% silt, 10% clay and 80% sand (sandy loam texture). The highest mean values (higher as 1) of the slenderness index were found in stands No. 1 and 2. This also shows a disproportionate relationship between height and diameter that indicates an unstable stand. Regarding the fact that the planting distance was 1 × 1 m in stands No. 1 and 2, it can be concluded that decreasing the planting distance caused an increase of the slenderness index value as a result of greater competition for light. The findings of this study are in accordance with those reported by DeBell et al. 2002 and Espahbodi et al. (2013), who concluded that trees with smaller planting interval had higher slenderness index values. The slenderness index mean was favourable in stands No. 5–7 (near one) and can be presented as a model for other stands. So it can be concluded that the planting interval 2 × 2 m at 30–40% soil saturation, content of silt 25–35%, clay 20–30% and sand 30–50% (loam texture) relates to a suitable slenderness index value (nearly one) and determines stand stability. According to the research of Marvie-Mohadjer (1975) there is a direct relationship between the slenderness index value and fertility of a site. Research by Kiadeliri et al. (2004) determined a significant difference between slenderness index values of poplar stands growing on different types of soil at the level of 1%. Gholizadeh et al. (2004) reported the maximum survival of *Acer velutinum* Boissier at the spacings of 2 × 2 and 3 × 3 m. Dorostkar (1984) and Amani et al. (1996) insisted on the planting distance of 2 × 2 m.

The highest mean commercial volume production mean was observed in stands No. 6 and 7 and they are significantly different in comparison with stands No. 1 and 2. Since stands No. 6 and 7 had planting interval of 2 × 2 m and stands No. 1 and 2 had planting interval of 1 × 1 m, it can be concluded that an increased planting interval was effective on increasing the commercial volume mean. The findings of this study are in accordance with the research reported in Espahbodi et al. (2013), who calculated the greatest volume increment at larger planting distance. Results of other research suggest that the planting distance of 2 × 2 m increases stem quality (Kerr, Evans 1993; Kerr 1995; Evans 1997) and study by Shujauddin and Mohan Kumar (2003) supported this issue. And also regarding the fact that the lowest mean of commercial volume production was observed in stands No. 3 and 4 and these stands were significantly different from stands No. 1 and 2. Regarding soil properties and the positive correlation between commercial volume production, soil saturation and silt percentage, and the negative correlation between commercial volume production and sand, it can be concluded that the greatest total volume production occurred in soil with 30–40% saturation, with content of silt 25–35%, clay 20–30% and also with content of sand 30–50% (loam texture) (Table 4). Furthermore, it can be concluded that the physical properties of soil had a greater effect on the commercial volume production of the investigated poplar stands than chemical properties of soil. Hemmati et al. (2014) determined that the heavy texture of soil (clay) was unsuitable for successful growth of poplar stands and Krinard and Johnson (1984) reported the maximum volume growth in soil with silty loam texture.

CONCLUSIONS

Finally, it can be concluded that the planting distance of 2 × 2 m can lead to increased commercial volume production, values of slenderness index and *P. nigra* stand stability while the planting distance of 1 × 1 m can increase the total volume of trees. In soil with 30–40% saturation, content of silt 25–35%, clay 20–30% and with sand content of 30–50% (loam texture), total volume production will increase and if the chemical properties of soil are appropriate, it will increase further because the soil has appropriate fertility. From investigated factors the soil properties are more important than the planting interval; vegetative characteristics showed the strongest correlation with physical properties of soil rather than with the chemical ones. If the purpose of poplar afforestation is the production of thick timber for industry, then the soil with loam texture which is rich in nutrients is recommended and planting distance of 2 × 2 m. However, if the purpose is to harvest thin wood and wood for fencing, then the poplar trees can be planted at higher density (1 × 1 m).

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