

Original article

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## Planting Spacing and Variation in Mechanical Properties of Poplar Wood (*Populus deltoids*)

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**Abstract.** Initial planting spacing affects stem diameter, tree height, and ultimately wood quality due to root and crown competition to reach light, water and nutrients. In the present study, we have investigated the effect of planting spacing and the longitudinal position along the stem height on wood density and mechanical properties of *Populus deltoids*. The study area has been located in the province of Mazandaran, in the north of Iran. 9 poplar trees (*Populus deltoids* Barter ex Marsh) have been randomly selected in 3 PS of the Sari (Mazandaran) Wood and Paper Factory plantation 2×2, 2×3 and 3×3 m. 3 disc samples have been taken at 3 positions along longitudinal direction from bottom to upward (breast height, 50, and 75 % stem height) to measure wood density and investigate its mechanical properties according to ISO and ASTM standard. Testing samples have been prepared from mature wood. The results of the research have shown that the planting spacing significantly influences wood density and mechanical properties. The effect of longitudinal position on the modulus of elasticity has been significant with no changes in the wood density, modulus of rupture, compression parallel to grain and nail withdrawal resistance values. The most optimal initial spacing in view of wood density and mechanical properties has been found at the planting spacing 2×2 m. Analysis of wood quality characteristics indicates that closer PS is more suitable for poplar plantation.

**Keywords:** *Populus deltoids*, planting spacing, longitudinal position along the stem height, wood density, mechanical properties of wood

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Научная статья

## Густота посадки и изменение механических свойств древесины на плантации тополя *Populus deltoids*

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**Аннотация.** Густота посадки оказывает влияние на диаметр ствола, высоту дерева и, в конечном счете, на качество древесины ввиду конкуренции корней и крон деревьев за свет, воду и питательные вещества. В настоящем исследовании изучено воздействие густоты посадки и положения древесины по высоте ствола на плотность древесины и ее механические свойства у *Populus deltoids*. Район исследования – провинция Мазендеран на севере Ирана. 9 деревьев тополя (*Populus deltoids* Barter.ex Marsh) были выбраны случайным образом на 3 участках плантации целлюлозно-бумажного комбината г. Сари (Мазендеран) размерами 2×2, 2×3 и 3×3 м. Для измерения плотности и учета механических свойств древесины использованы 3 образца дисковой формы, взятые в 3 положениях в продольном направлении по высоте дерева снизу вверх (высота на уровне груди, 50 и 75 % высоты ствола). В соответствии с требованиями стандартов Международной организации по стандартизации (ISO) и Американского общества испытаний и материалов (ASTM), образцы изготовлены из зрелой древесины. Результаты исследования продемонстрировали существенное влияние густоты посадки на плотность и механические свойства древесины. Влияние положения древесины по высоте ствола на модуль упругости оказалось значительным, при этом плотность, предел прочности при изгибе, сжатие вдоль волокон и сопротивление выдергиванию гвоздя не изменились. Оптимальная первоначальная густота посадки с точки зрения плотности древесины и ее механических свойств была обнаружена на участке площадью 2×2 м. Анализ качественных характеристик древесины установил, что для посадки тополя больше подходит размещение с меньшим шагом.

**Ключевые слова:** *Populus deltoids*, густота посадки, положение древесины по высоте ствола, плотность древесины, механические свойства древесины

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### Introduction

Due to the increasing demand for wood and the limitation of wood harvesting from natural forests in Iran, the need for forest plantations and agroforestry systems with fast-growing and preferably endemic species has become urgent [32]. Poplar (*Populus sp.*) is one of the most valuable and high-yielding tree species in the world and is an important wood supply source in Iran. It has a high growth rate and short harvesting term, which is why it is highly used in wood and paper industry [32]. *Populus deltoids* (the *Salicaceae* family) is native to North America and introduced to Europe, Australia and Southeast Asia [34, 35].

Intensive management in plantations affects growth features, biomass and wood properties of different tree species. Lei et al. (1997), DeBell et al. (2002), Naji et al. (2013), and Naji et al. (2015) have investigated wood quality using red alder (*Alnus rubra*), poplar (*Populus spp.*), rubber tree (*Hevea brasiliensis*) and maple (*Acer velutinum*) wood, respectively, as examples [8, 22, 27, 28]. Numerous studies have examined the effects of silvicultural practices on wood properties of different tree species. Tree spacing is one of the most common stand parameters for controlling the tree growth. The most important goals of choosing optimal tree spacing, according to foresters, are to increase the diameter of a tree stem, as well as improve wood properties and increase forest production in terms of wood quality [42, 43].

In a well-managed plantation, trees receive more light, nutrients and water; the suppressed trees are removed in order to make enough space for quality trees [7]. Suitable planting distances ensure the required space for tree growth and optimize biomass production per unit area [13]. However, it is little-known how tree growth alters wood and fiber characteristics in poplar. Therefore, knowing the relationship between planting spacing and tree and wood characteristics can help foresters to maximize biomass production without lowering wood quality. In this direction, Riahiifar et al. (2009) have reported a significant variance in longitudinal and diameter growth in poplar and paulownia species at different initial spacings [34]. The height and stem diameter of poplar trees has decreased with increasing the initial spacing due to high light competition. Khan and Chaudhry (2007) have determined the effect of an increase in the initial spacing from  $6.1 \times 3.7$  to  $3.7 \times 12.1$  m on the growth rate (tree diameter and longitudinal growth) of *Populus deltoids* in Pakistan [17]. Hosseinzadeh et al., (1998) have examined the effect of initial spacing on annual ring width and wood properties of 2 clones of *Populus deltoids* and have reported a significant influence of initial spacing on wood density, fiber length, annual growth, diameter at breast height, tree height, branch density, and bark weight. The lowest wood density has been recorded in the 1st log (near the stump) and the highest – in the top log (near the crown). The variation of fiber length along longitudinal direction from the base to the 3rd log has had ascending and descending trends in the crown log [14]. Naji et al. (2015) have determined no significant effect of initial spacing of *Acer velutinum* on physical properties and fiber biometrical features such as wood density, fiber length, diameter and cell wall thickness [27]. Afhami et al. (2012) have evaluated the effect of agroforestry practices on *Populus nigra* wood physical properties along longitudinal and radial direction and have reported that wood density and volumetric shrinkage have increased with an increase in initial planting spacing. Furthermore, wood density and volumetric shrinkage have decreased along the stem from the base upwards and have increased in longitudinal shrinkage [1]. Guler et al. (2015) have reported that ash wood grown in wider spacings possesses high mechanical properties. In other words, the mechanical properties (compression strength parallel to grain, tensile stress perpendicular to grain, bending strength, impact bending strength and modulus of elasticity) of wood have increased with an increase in the planting spacings (PSs) from  $3 \times 2$  to  $4 \times 4$  m [12].

Some researchers have reported on the physical properties [21], biometric features [31, 41], and papermaking properties [15] of poplar wood, but there is little research on the effect of initial spacing on poplar wood properties. Therefore, the present study has aimed to investigate the effect of different initial spacing as well as longitudinal position (LP) along the stem height on wood density and mechanical properties of *Populus deltoids*.

#### *Research Objects and Methods*

The *Populus deltoids* Barter.ex Marsh trees have been randomly taken from a trial 22-year-old plantation planted by Wood and Paper Industry Factory located in Sari ( $53^{\circ}3'41''$  E and  $36^{\circ}19'19''$  N), Mazandaran Province, Iran at 3 PSs  $2 \times 2$ ,  $2 \times 3$  and  $3 \times 3$  m. For 30 random trees from all 3 PS, height and stem diameter have been measured.

To examine the wood properties of the plantation, 3 trees have been sampled from each PS (in total, 9 trees) and sample discs have been taken at breast height ( $\approx 1.30$  m), 50 %, and 75 % of the total tree height (Table 1). The samples have been prepared from near the bark in accordance with the ISO 3129-1975 (E) Standard (International Organization for Standardization (ISO), 1975a).

Table 1

Basic information on the *Populus deltoids* plantation

|                                |                        |       |       |
|--------------------------------|------------------------|-------|-------|
| Planting spacing (PS)          | 2×2                    | 2×3   | 3×3   |
| PD, trees per ha <sup>-1</sup> | 2,500                  | 1,666 | 1,111 |
| TH, m                          | 22.45                  | 19.78 | 20.83 |
| DBH, cm                        | 18.43                  | 15.51 | 16.77 |
| Altitude, m                    | 100                    |       |       |
| Temperature, °C                | 15                     |       |       |
| AP, mm                         | 789                    |       |       |
| Soil texture                   | Silt clay to clay loam |       |       |

Note: PD – planting density; TH – tree height; DBH – diameter at breast height; AP – annual precipitation.

*Wood density (WD).* To determine wood density, the samples have been respectively prepared in accordance with the ISO–3131 Standard (1975). The initial weight and dimensions of the samples have been measured. After that, the samples have been dried at a temperature of  $103 \pm 2$  °C for 24 hours, and then the oven-dry weight and the dimensions of the samples have been measured with digital balance and Vernier caliper (with an accuracy of 0.001). Finally, wood density has been calculated as a ratio of oven-dry weight to dry volume [20].

*Mechanical properties.* From each tree, logs have been taken from breast height to calculate static bending parameters: modulus of rupture (MOR), modulus of elasticity (MOE), compression parallel to grain (CPG) and nail withdrawal resistance (NWR), respectively. The testing samples have been taken from near the bark in accordance with the ASTM-D143–94 Standard. The samples have been conditioned in  $65 \pm 3$  % relative humidity and  $20 \pm 2$  °C temperature for at least 4 weeks before testing, until they have reached the equilibrium moisture content of about 12 %.

*Statistical analysis.* The interaction effect of initial spacing and longitudinal position along the stem height on the wood density and mechanical properties of *Populus deltoids* have been measured. Data analysis has been performed using SPSS statistical software ver. 20, and 2-way analysis of variance in a completely randomized design. Comparison and grouping of means has been performed via Duncan’s test at 95 % confidence level.

Results and Discussion

The results of the analysis of variance (ANOVA) of wood density and mechanical properties of poplar wood are represented in Table 2.

Table 2

The results of the ANOVA of poplar wood properties

| Wood properties | PS (A) |        | LP (B)  |        | A × B  |        |
|-----------------|--------|--------|---------|--------|--------|--------|
|                 | F      | Sig    | F       | Sig    | F      | Sig    |
| WD              | 3.897  | 0.024* | 1.852   | 0.162  | 2.110  | 0.086  |
| MOR             | 43.240 | 0.000* | 1.630   | 0.200  | 3.670  | 0.010* |
| MOE             | 10.500 | 0.000* | 21.540  | 0.000* | 1.420  | 0.240  |
| CPG             | 3.590  | 0.038* | 430.000 | 0.650  | 14.790 | 0.000* |
| NWR             | 46.250 | 0.000* | 0.820   | 0.440  | 1.420  | 0.240  |

Note: \* – significant at 5 %; LP – longitudinal position along the stem height; MOR – modulus of rupture; MOE – modulus of elasticity; CPG – compression parallel to grain; NWR – nail withdrawal resistance; F – F-value from ANOVA; Sig – significance level. Degree of freedom is 2.

*Wood density.* The results of the analysis of variance (ANOVA) have shown that the PS has significantly affected the WD of *Populus deltoids* (Table 2). The independent effect of LP and the PS × LP effect on WD have not been significant. WD has been decreasing with increasing the PS. The mean WD values at the PSs 3×3 (0.397 g/cm<sup>3</sup>) and 2×3 m (0.389 g/cm<sup>3</sup>) have fallen into one group and the ones at the PS 2×2 m (0.401 g/cm<sup>3</sup>) into another (Table 3).

WD is of the most important physical properties of wood that relates to other wood properties [38]. In general, changes in the density of diffuse-porous hardwoods are not dependent on the growth rate, but on the anatomical structure of wood such as fiber cell wall thickness, early-late wood ratio, vessel, fiber, and parenchyma percentages [43]. The direct relationship between cell wall thickness and density and the converse relationship between vessel percentage and density have been demonstrated by some researches [5, 29, 43]. WD has been decreasing with an increase in the PS. An increase at the PS 2×2 m is highly related to an increase in cell wall thickness [36]. The cell wall thickness has been 4.57 μm at the PS 2×2 m, 3.87 μm at the PS 2×3 m and 4.23 μm at the PS 3×3 m [19].

The process of changing WD with the initial spacing is still debated. No significant effect of the PS has been found for maple wood [27], eucalyptus wood [9], *Schizolobium parahyba* wood [26] and *Tectona grandis* wood [23]. A direct relation between planting spacing and WD has been found for poplar wood [14]. For the current study, significant differences have been observed only for WD, starting from increasing the PS from 2×2 to 3×3 m. These discrepancies are probably due to differences in the species being evaluated, as well as in the environmental conditions, and the extent of the PSs tested [37].

Although the effect of the LP on WD has not been significant (Table 2), a decreasing trend in this parameter has been observed along the stem from the base upwards (Table 3). A decreasing trend along longitudinal direction has been supported by Repola (2006) for *Betula pendula* and *B. pubescens* [33]; Izekor et al. (2010) for *Tectona grandis* [16]; Zeidler (2012) for *Corylus colurna* [40]; Kiaei and Farsi (2016) for *Albizia julibrissin* [18]; Kord et al. (2010) for *Populus euramericana* [21]; Topaloglu and Erisir (2018) for *Fagus orientalis* [37], and by Mahmud et al. (2017) for *Neolamarckia cadamba* [25]. In contrast, Otoide (2016) has reported an increase in WD with the longitudinal position in *Azelia Africana* trees [30]. Chowdhury et al., (2007) have also observed no significant differences among different parts of the stem (butt, center, and crown) of *Casuarina equisetifolia* [6]. Machado et al.

(2014) have reported an increase in WD with the height level especially from 35 to 65 % of the tree height for blackwood (*Acacia melanoxylon*) in Portugal [24]. Githio-mi and Kariuki (2010) have revealed that the basic WD of *Eucalyptus grandis* has been decreasing from the base to breast height and then reaching its maximum at the 60 % height point [11]. These changes can be related to wood species, as well as environmental and climatic conditions [36, 37]. In this study, poplar WD along lon-gitudinal direction has varied from 0.390 to 0.398 g cm<sup>-3</sup> for all the 3 PSs.

Table 3

The descriptive statistical data on poplar WD

| PS, m                               | LP   | WD,<br>g/cm <sup>-3</sup> | CPG,<br>MPa | MOR,<br>MPa | MOE,<br>MPa | NWR,<br>kg/cm |
|-------------------------------------|------|---------------------------|-------------|-------------|-------------|---------------|
| 2×2                                 | DBH  | 0.386                     | 32.00       | 89.00       | 8,200       | 310.00        |
|                                     | 50 % | 0.414                     | 33.00       | 92.00       | 9,000       | 370.00        |
|                                     | 75 % | 0.410                     | 34.00       | 95.00       | 9,900       | 320.00        |
|                                     | Mean | 0.401 B                   | 33.00 A     | 92.00 A     | 9,033 A     | 333.33 A      |
| 2×3                                 | DBH  | 0.387                     | 28.00       | 70.00       | 7,100       | 250.00        |
|                                     | 50 % | 0.390                     | 27.00       | 75.00       | 7,800       | 300.00        |
|                                     | 75 % | 0.392                     | 29.00       | 70.00       | 7,700       | 250.00        |
|                                     | Mean | 0.389 A                   | 28.00 B     | 72.50 B     | 7,533 C     | 266.67 B      |
| 3×3                                 | DBH  | 0.401                     | 30.00       | 89.00       | 7,700       | 290.00        |
|                                     | 50 % | 0.393                     | 32.00       | 91.00       | 8,300       | 320.00        |
|                                     | 75 % | 0.396                     | 31.00       | 92.00       | 9,000       | 310.00        |
|                                     | Mean | 0.397 AB                  | 31.00 A     | 90.67 A     | 8,333 B     | 306.67 A      |
| Mean of wood<br>properties<br>in LP | DBH  | 0.390                     | 30.00       | 82.67       | 7,666 c     | 283.33        |
|                                     | 50 % | 0.397                     | 30.67       | 86.00       | 8,366 b     | 330.00        |
|                                     | 75 % | 0.398                     | 31.67       | 85.67       | 8,866 a     | 293.33        |

Note: The capital letters indicate significance in the 3 PSs; capital letters indicate the mean groupings of wood properties among PSs, while small letters indicate the mean groupings of wood properties along the stem height.

*Mechanical properties.* MOR and MOE are the 2 crucial mechanical proper-ties that should be carefully considered and related to WD [39]. MOE, or stiffness, is a measure of deformation that wood undergoes when subject to an applied load, and it is measured as a ratio of stress and strain. It is a property of particular interest to growers and processors of structural lumber as it determines the end-use and value of lumber cut from a tree [2].

*Compression parallel to grain.* The results of the ANOVA have shown the significant effect of PS on the CPG (Table 2). The independent effect of LP and the PS × LP effect on the CPG of *Populus deltoids* wood have not been significant. The CPG value in poplar species at the PS 2×2 m has been higher compared to the ones measuring 2×3 and 3×3 m (Table 3).

According to Bozkurt and Erdin (1990), the classes of CPG are listed as: < 20 MPa – very small, 20–35 MPa – small, 35–55 MPa – medium, 55–85 MPa – high, and > 85 MPa – very high. The mean CPG has been found to be 33MPa for the PS 2×2 m, 28 MPa for the one measuring 2×3 m and 31 MPa for the one measur-ing 3×3 m [4]. According to this, poplar belongs to the group of trees with small CPG.

An insignificant increasing trend for CPG has been observed along the stem from the base upwards, in this study (Table 3). This result has been previously report-

ed by Machado et al., (2014) for blackwood [24]. They have revealed that the CPG of blackwood grown in Portugal does not vary with the longitudinal position (5, 35 and 65 % of stem height). In contrast to these findings, Topaloglu and Erisir (2018) have detected a decreasing trend in the CPG from the height of 1.30 to 12.30 m for beech wood in Turkey [37]. Also, Izekor et al. (2010) have observed a decreasing trend in the CPG from the base to the top for *Tectona grandis* wood [16].

*Modulus of rupture.* The results of the ANOVA have demonstrated the significant effect of PS on the MOR (Table 2). The independent effect of LP and the PS  $\times$  LP effect on the MOR of *Populus deltoids* wood have not been significant. The MOR value in poplar species in the PS 2 $\times$ 2 m (92MPa) has been higher compared to the ones in the PSs 2 $\times$ 3 (72.5 MPa) and 3 $\times$ 3 m (91 MPa) (Table 3).

According to Bozkurt and Erdin (1990), the classes of MOR are listed as: <50 MPa – very small, 50–85 MPa – small, 85–120 MPa – medium, 120–175 MPa – high, and > 175 MPa – very high [4]. According to this classification, poplar wood in the PS 2 $\times$ 2 and 3 $\times$ 3m falls under the 3rd category (medium) and in the one measuring 2 $\times$ 3 m – under the 2nd category (small).

*Modulus of elasticity.* The statistical analysis has shown the significant effect of PS and LP on the MOE (Table 2). The PS  $\times$  LP effect on the MOE of *Populus deltoids* wood has not been significant. The MOE value in poplar species at the PS 2 $\times$ 2 (9,033 MPa) has been higher compared to those in the PS 2 $\times$ 3 (7,533 MPa) and 3 $\times$ 3 m (8,333 MPa). MOE along the stem has been increasing from the base upwards (Table 3).

According to Bozkurt and Erdin (1990), the classes of MOE are defined as: < 6,000 MPa – very small, 6,000–10,000 MPa – small, 10,000–13,000 MPa – medium, 13,000–16,000 MPa – high, and > 16,000 MPa – very high. The overall mean MOE for poplar wood has been found to be 8,300 MPa [4]. According to the classification above, poplar wood at all the 3 PSs belong to the “small” category.

*Nail withdrawal resistance.* The results of the ANOVA have demonstrated the significant effect of PS on the NWR (Table 2). The independent effect of LP and the PS  $\times$  LP effect on the NWR of *Populus deltoids* wood have not been significant. The NWR value in poplar species at the PS 2 $\times$ 2 m has been higher compared to the ones in the PSs 2 $\times$ 3 and 3 $\times$ 3 m (Table 3).

The data obtained has indicated that the highest and lowest MOE, MOR, CPG and NWR in wood have been found at the PSs 2 $\times$ 2 and 2 $\times$ 3 m, respectively. The mechanical properties of wood largely depend upon its density and microfibril angle (MFA) [7, 10]. The high MFA and low WD values at the PS 2 $\times$ 3 m are associated with low mechanical properties of wood, and the low MFA and high WD values – with high mechanical properties at the PS 2 $\times$ 2 m. Also, density is the most important physical characteristic determining the compression strength of a wood sample, and a significant correlation between density and compression strength exists [12]. Moreover, there are more material distributed internal stresses in dense wood, so the mechanical properties of wood are also increasing [3]. In the present study, a declining trend in mechanical properties at the PSs 2 $\times$ 2 and 2 $\times$ 3 m can be related to the correlation mentioned above.

### Conclusion

The effect of initial spacing on WD and mechanical properties has been found to be significant. The mean dry WD and mechanical properties at the PS 2 $\times$ 2 m

has been higher than at the others. The lowest WD and mechanical properties have been found at the PS 2×3 m. LP has been revealed to significantly effect the MOE. The trend in the variation of MOE along LP direction from the base upwards has been towards increasing. The poplar plantation with low spacing is recommended due to higher WD, favorable mechanical properties and higher volumes of wood production in short rotation periods compared to other PS.

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