EFFECT OF INITIAL SPACING ON GAS PERMEABILITY OF *POPULUS NIGRA* VAR. *BETULIFOLIA*

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TAGHIYARI HR, EFHAMI D, KARIMI AN & POURTAHMASI K. 2011. Effect of initial spacing on gas permeability of *Populus nigra* var. *betulifolia*. Initial spacing during planting affects growth rate of trees and consequently influences various properties of wood. Permeability is an important property of wood that determines many of its applications. The present study was therefore focused on the effect of initial spacing on gas permeability of *Populus nigra* var. *betulifolia* in connection with its vessel properties. Treatments included four initial spacings of the poplar cuttings at 3 × 4, 3 × 6.7, 3 × 8 and 3 × 10 m of 10-year-old poplar trees, intercropped with alfalfa. Specific gas permeability values were measured at breast height in longitudinal and radial directions. Maximum longitudinal permeability value was 1631.26×10^{-13} m^3 m^{-1} for the 3 × 10 m treatment where maximum vessel lumen diameter was found to be 67.09 µm. Minimum longitudinal permeability was in the 3 × 4 m treatment with a value of 1052.15×10^{-13} m^3 m^{-1} where minimum vessel lumen diameter was observed (63.17 µm). Vessel lumen area decreased by 10.2% as the initial spacing increased from 3 × 4 to 3 × 10 m but a clear positive relation was still found between initial spacing and gas permeability. Therefore, it can be concluded that vessel lumen diameter was more influential in the determination of gas permeability than percentage of vessel lumen area.

Keywords: Poplar, porous media, silviculture, vessel properties

TAGHIYARI HR, EFHAMI D, KARIMI AN & POURTAHMASI K. 2011. Kesan jarak tanaman awal terhadap kebolehtelapan gas *Populus nigra* var. *betulifolia*. Jarak tanaman awal mempengaruhi kadar pertumbuhan pokok dan seterusnya mempengaruhi pelbagai ciri kayu. Kebolehtelapan merupakan ciri penting yang menentukan penggunaan kayu. Kajian ini bertumpu pada kesan jarak tanaman awal terhadap kebolehtelapan gas *Populus nigra* var. *betulifolia* dari segi ciri-ciri veselnya. Uji kaji melibatkan empat jarak tanaman awal keratan poplar iaitu 3 m × 4 m, 3 m × 6.7 m, 3 m × 8 m dan 3 m × 10 m bagi pokok poplar berusia 10 tahun yang diselingkan dengan alfalfa. Nilai kebolehtelapan gas spesifik pokok poplar disukat pada aras dada pada arah membujur dan arah jejari. Nilai kebolehtelapan membujur maksimum ialah 1631.26×10^{-13} m^3 m^{-1} untuk jarak 3 m × 10 m yang turut menunjukkan diameter lumen vesel maksimum dengan nilai 67.09 µm. Kebolehtelapan membujur minimum dicerap pada jarak 3 m × 4 m dan nilainya ialah 1052.15×10^{-13} m^3 m^{-1}. Jarak ini juga mempamerkan diameter lumen vesel minimum iaitu 63.17 µm. Luas lumen vesel berkurangan sebanyak 10.2% apabila jarak awal meningkat dari 3 m × 4 m ke 3 m × 10 m. Namun hubungan positif yang jelas tetap wujud antara jarak tanaman awal dengan kebolehtelapan gas. Oleh itu, bolehlah disimpulkan bahawa diameter lumen vesel lebih kuat mempengaruhi penentuan kebolehtelapan gas berbanding luas lumen vesel.

INTRODUCTION

Poplar hybrids and clones which are grown on intensively-managed plantations are able to reach sawn-timber size and are harvested at a younger age (Dickmann 2006). Initial spacing is one of the most important silvicultural factors used to control tree growth and wood quality. The spacings alter growing conditions in utilisation of nutrients, water and sunlight which will eventually affect the characteristics of the wood produced (Zobel & Van Buijtenen 1989, Zhang et al. 2002). In this connection, understanding wood permeability is of vital importance and has great impact on wood utilisation in different industries such as wood preservation, wood drying, and pulp and paper. Permeability is influenced by porosity and capillary structure of wood (Siau 1995).

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It was reported in a previous study that there was no significant correlation between different diameter growth rates caused by tree–tree competition and percentage of vessel lumen area in three hardwoods, namely, northern red oak, black walnut and yellow poplar (Chen et al. 1998). However, increased permeability was observed in yellow poplar as growth rate increased. Thus, Chen et al. (1998) concluded that other factors may also be involved in the increase in longitudinal sapwood permeability; these factors may include vessel lumen diameter and the type of perforation plates between vessel elements. In another study involving six-year-old *Populus deltoides* trees, it was also observed that increase in growth rate resulted in more vessel diameter and consequently increased permeability values (Doungpet 2005). Clear direct relation was also reported between intercropping with alfalfa and diameter increment as well as longitudinal permeability (Taghiyari & Efhami 2011). However, the possible relationship between gas permeability and vessel properties of different initial spacings in poplar clones has not been widely studied. Therefore, the present study was aimed at determining the relationship between gas permeability and vessel properties of poplar planted at four different initial spacings. By understanding the possible relationship between the effects of initial spacing on vessel properties, and the consequent effect of variation in vessel properties on permeability of the wood, the end-use of the wood produced would be better managed.

MATERIALS AND METHODS

Materials and study area

Twelve 10-year-old trees of *Populus nigra* var. *betulifolia* from Karaj, Iran (35° 48' N, 50° 54' W, 1300 m above sea level) were used for this study. Mean annual rainfall and temperature of the area are about 230 mm and 13.7 °C respectively. The soil is alluvial sandy clay, moderately alkaloid (pH 8), with an average nitrogen concentration of about 0.07% in the topsoil (0–25 cm). The trees were planted in plots of 1200 m^2 per treatment in a randomised complete block design comprising four initial spacings (3 × 4, 3 × 6.7, 3 × 8 and 3 × 10 m) of poplar trees intercropped with alfalfa as N-fixing plant. Three trees were selected from each treatment and cut. The planting of alfalfa was continued only for the first five years because during the next five years the canopy of trees did not allow enough sunlight to reach the alfalfa for proper growth.

Growth rate measurement

Discs were cut from the poplar at breast height and then air dried. Annual growth rings were measured with 0.01 mm precision using a LINTAB5 measuring table. Data obtained were then transferred to a connected computer set to be processed by TSAPWin (RINNTECH) software.

Vessel properties

A pith-to-bark strip of about 1 cm wide and 1.5 cm thick was cut along the average diameter to measure vessel attributes. After soaking in hot distilled water for 24 hours, the strip was cut to its individual tree rings with a sharp chisel. Cross-sections (15 μm thick) were cut from these samples with a sliding microtome, stained with safranine, dehydrated in a graded alcohol series and finally mounted in Canada balsam. Four fields in each direction (maximum and minimum growth rate directions) were selected for manual analysis by light microscopy and, thus, eight fields from each growth ring were measured. Each growth ring was subdivided into four zones from pith to bark in each direction. Each zone covered 20% of the distance between the start of the earlywood up to the end of latewood. The number of vessels in the 0.4 mm^2 fields was counted (Efhami et al. 2010). The maximum and minimum vessel lumen diameters for all vessels in each field were measured and averaged. As to the treatment and the age of growth ring, the number of vessels in each field (i.e. the 0.4 mm^2) varied from approximately 20 to 50 vessels. Percentage of vessel lumen area was then calculated based on vessel frequency and vessel lumen diameter in each field. Averaging was done based on weighting individual ring vessel properties by ring areas. The proportion of each growth ring area was measured in comparison with the whole disc area to obtain weighting coefficient for every growth ring. Averaging vessel properties was then done using these weighted coefficients.

Gas permeability measurement

Discs were kept in a conditioning chamber to reach a moisture content level of 10.0% before gas permeability specimens were cut from them. In the present study, specimens used were cylindrical, 18 mm in diameter and, because of technical reasons, 30 mm long, although 50-mm long specimens gave better scope of specific gas permeability values in wood (Taghiyari & Sarvari 2010). Specimens were free from any knots, checks and splits. From each disc, 20 specimens were cut randomly at scattered locations.

Gas permeability was measured using falling water displacement volume method (Siau 1971, Taghiyari et al. 2010). In this method, gravity provides the necessary vacuum pressure for the fluid, i.e. air to pass through the specimens. The value of vacuum pressure is dependent on the diameter of the water column as well as the length of water column. The greater the diameter and length, the greater the vacuum pressure. Specimens were tightly connected to the apparatus so that fluid could only pass through the specimens. A pressure gauge was connected to the apparatus to monitor pressure gradient (ΔP) and vacuum pressure at any particular time and height of water column.

Three measurements were taken for each specimen for time measurements. Superficial permeability coefficient was then calculated using Siau's equations (equations 1 and 2) (Siau 1995). The superficial permeability coefficients were then multiplied by the viscosity of air ($\mu = 1.81\times10^{-5}$ Pa s) to determine the specific permeability ($K = k_g\,\mu$).

$$k_g = \frac{V_d CL\,(P_{atm} - 0.074\bar{z})}{tA\,(0.074\bar{z})(P_{atm} - 0.037\bar{z})} \times \frac{0.760\ \text{m Hg}}{1.013\times10^6\ \text{Pa}} \qquad (1)$$

$$C = 1 + \frac{V_r\,(0.074\,\Delta z)}{V_d\,(P_{atm} - 0.074\,\bar{z})} \qquad (2)$$

where

k_g = longitudinal permeability ($m^3\ m^{-1}$)
V_d = $\varpi\, r^2 \Delta z$ (r = radius of measuring tube (m)) (m^3)
C = correction factor for gas expansion as a result of change in static head and viscosity of water
L = length of wood specimen (m)
P_{atm} = atmospheric pressure (m Hg)
$\bar{z}$ = average height of water over surface of reservoir during period of measurement (m)
t = time (s)
A = cross-sectional area of wood specimen (m^2)
Δz = change in height of water during time t (m)
V_r = total volume of apparatus above point 1 (including volume of hoses) (m^3)

Permeability was also calculated using Poiseuille's law of viscous flow which applies to gases through hardwood vessels (equation 3) (Siau 1971).

$$k_l = \frac{n\pi R^4}{8\eta} \times 1.013 \times 10^6 \qquad (3)$$

where

k_l = longitudinal permeability (cm^3 (fluid) $cm^{-1}\ atm^{-1}\ sec^{-1}$)
1 atm = 1.013×10^6 (dyne cm^{-2})
R = radius of vessels (cm)
n = N/A = number of vessels per cm^2 of cross section
η = viscosity of fluid (dyne sec cm^{-2})

Statistical analysis

Statistical analysis was conducted using SPSS software program, version 15. One-way ANOVA was performed to conclude significant difference at 95% confidence level. Grouping was then made between treatments using the Duncan's multiple range test.

RESULTS AND DISCUSSION

Growth rate

Results of growth rate showed that wider initial spacings had a positive effect on diameter growth of trees (Table 1). Maximum (19.27 mm) growth rate was observed in the 3 × 10 m treatment for 10 growth rings and minimum (13.75 mm), in the 3 × 4 m treatment. Wide initial spacing decreases competition among individual trees (Wodzicki 2001) and consequently increase growth rate. In a similar study of intercropping with wheat–fodder maize crops and tree spacings, positive effect on poplar tree growth was also observed (Chaudhry 2003). Radial variation of growth rate showed nearly the same trend in all four treatments (Figure 1). The tree growth pattern observed in the present study was also reported by other researchers (Taghiyari et al. 2008, DeBell et al. 1998, 2002). In any plantation, the ring width generally decreases with age because of the increased competition with surrounding trees (Wodzicki 2001); in poplar plantations, this decrease in ring width is usually observed in rings 3 to 5.

Vessel properties

Increase in initial spacing had an increasing effect on vessel lumen diameter but a decreasing effect on the percentage of vessel lumen area (Table 1). Vessel lumen diameter increased by 7.2% and vessel lumen area decreased by 10.2% from 3 × 4 to 3 × 10 m treatments. The increase in vessel lumen diameter and decrease in vessel lumen area were caused by the reduction in vessel lumen frequency (Table 1).

Gas permeability

A clear increasing trend in gas permeability was observed from the closest to the widest initial spacing (Figure 2). The 3 × 4 m treatment showed minimum (1052.15 × 10^{-13} m^3 m^{-1}) longitudinal gas permeability while the 3 × 10 m treatment, the maximum (1631.26 × 10^{-13} m^3 m^{-1}). Simple correlation analysis between gas permeability and growth rate showed a great correlation coefficient of as much as 0.87. A similar trend was observed for the specific radial gas permeability. The 3 × 4 m treatment showed the minimum (0.334 × 10^{-13} m^3 m^{-1}) value while the 3 × 10 m treatment, the maximum (0.674 × 10^{-13} m^3 m^{-1}) (Figure 3).

The trees in this research were 10 years old. This meant that the whole disc was located in juvenile wood zone (Taghiyari et al. 2008). It has been proven that wider initial spacings decrease competition among individual trees and consequently increase growth rate (Wodzicki 2001). In another study, a positive, but low, correlation was reported between growth rate and vessel lumen diameter (Doungpet 2005). A comprehensive study on vessel properties of the same trees as the present research (Efhami et al. 2010) proved that a higher growth rate, caused by

Table 1 Description of four spacing treatments and their relevant growth rates and vessel properties

Spacing (m)	No. of trees plot^{-1}	No. of trees ha^{-1}	Area of each plot (m^2)	Growth rate (mm)	Vessel diameter (μm)	Vessel lumen area (%)	Vessel frequency (mm^2)
3 × 4	121	833	1200	13.75 cd	66.9 b	35.3 a	103 a
3 × 6.7	77	500	1200	14.94 bc	68.8 ab	32.9 ab	90 ab
3 × 8	66	416	1200	16.39 b	68.5 ab	32.7 ab	89 ab
3 × 10	55	333	1200	19.27 a	71.7 a	31.7 ab	79 b

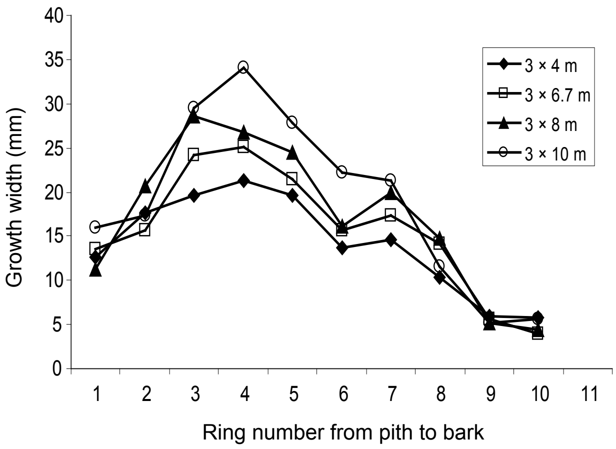

Figure 1 Growth rate for the four initial spacings

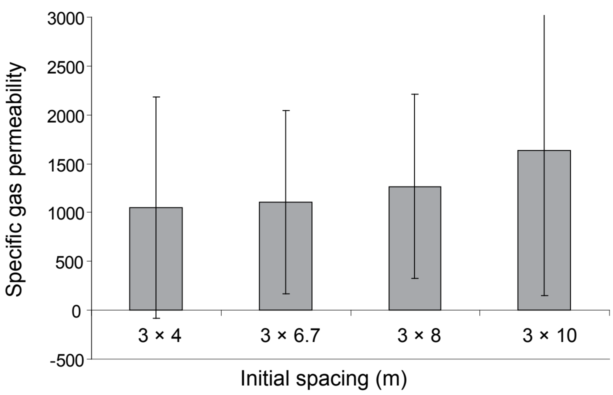

Figure 2 Specific longitudinal gas permeability values (× 10^{-13} m^3 m^{-1}) for four different initial spacings

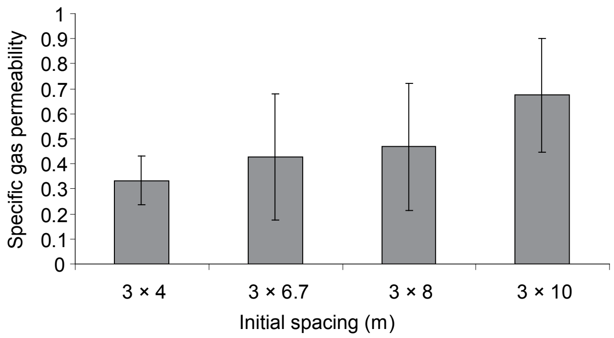

Figure 3 Specific radial gas permeability values ($\times 10^{-13}$ m^3 m^{-1}) for four different initial spacings

increase in initial spacing, increased vessel lumen diameter and, naturally, gas permeability would be expected to improve. However, results of the present study only showed that longitudinal permeability increased as much as 55.0% from 3 × 4 to 3 × 10 m, but vessel lumen diameter increased by only 7.2 % (Figure 2, Table 1).

The percentage of vessel lumen area showed a 10.2% decrease from 3 × 4 to 3 × 10 m; it should have therefore resulted in less permeability but, in practice, more permeability was measured in 3 × 10 m. On the other hand, vessel lumen diameter only increased by 7.2% from 3 × 4 to 3 × 10 m, while permeability increased by 55%. In this regard, Poiseuille's law of viscous flow proves that there is positive relationship between permeability value and the fourth exponent (R^4) of the radius of capillary. The fourth exponent of the radius implies that a slight increase or decrease in vessel radius may have a high impact on gas permeability. It may thus be concluded that the impact of vessel lumen diameter will be far more effective in gas permeability than vessel lumen area. A similar conclusion was made for longitudinal gas permeability values in *Populus deltoides* and *Populus* × *euroamericana* (Taghiyari et al. 2010). Simple correlation analysis between gas permeability and vessel lumen diameter and area also concurs with this finding.

Error bars in Figures 1 and 2 showed great standard deviations. Concentration of extractive content and/or pitch deposit that blocks vessel perforations and pits is not the same in different parts of a tree and, therefore, permeability values will also vary significantly (Taghiyari et al. 2010). Furthermore, juvenile wood tends to have great fluctuations in its properties (Zobel & Spargue 1998) and this can be another reason for the great standard deviation in permeability values.

CONCLUSIONS

The present study proves that there is a direct relationship between initial spacing and gas permeability. Therefore, for industries needing great permeability values such as wood preservation and pulp and paper industries, a wider initial spacing is recommended.

The results of the present study also prove that vessel lumen diameter is far more effective in the prediction and evaluation of gas permeability than the percentage of vessel lumen area.

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