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# APPROPRIATE TREE SPECIES FOR INTENSIVE FOREST PLANTATIONS IN CENTRAL NORTHERN BULGARIA

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## Abstract

The ever-growing demand for timber and restricted harvesting in oak and beech forests resulted in the idea of establishment of fast-growing forest tree plantations. The present paper presents results of a study on the plantations established in 1984 and 1985 in State Forest Service (SFS) Gorna Oryahovitsa, near the village Paisiy. The experiment consisted of pure plantations of *Pseudotsuga menziesii* (Mirb.) Franco, *Cedrus atlantica* Manetti, *Quercus rubra* L., *Tilia tomentosa* Moench., *Robinia pseudoacacia* L. and *Pinus nigra* Arn., and mixed plantations of *Cedrus atlantica*, *Quercus rubra* and *Tilia tomentosa*. All species were planted in three different locations. *Robinia pseudoacacia* plantations with initial density 2 x 1 m, and natural *Quercus cerris* – *Q. frainetto* stand were used as control. The intensive plantations were more productive than both conventional stands and natural forest. At the age of 20 to 21 the target species were in good health, grew well, and did not show any signs of deteriorating health. Highest increment was recorded in the pure plantations of *Tilia tomentosa*, *Pseudotsuga menziesii* and *Pinus nigra*. The research proved that intensive forest plantations are especially suitable for the lower forest belt if they are planted on suitable locations and the soil is appropriately cultivated.

**Key words:** growth, initial density, intensive plantations, increment.

## Introduction

The ever-growing demand for timber and the intensive deforestation of woodland on a national and global scale needs efficient solutions of this problem. The exploitation of high-stem oak and beech forests, as well as forests of other valuable species, should be restricted. The possibilities for establishment of fast-growing polar plantations are limited due to the few available areas suitable for this purpose. In the 1970s scientists came up with the idea of establishment of industrial plantations of fast-growing tree species in the lowland forest zone. This, through intensive cultivation, would provide production of small, medium-sized and some large-sized logs for a period of 25 to 30 years. In 1973 the Government decreed that the Ministry of Forestry should establish a total area of 150,000 hectares of intensive plantations – 90,000 ha in North Bulgaria and 60,000 ha in South Bulgaria.

Possibilities for establishing forest plantations for accelerated timber production at early age were studied among others by Broshtilova et al. (1988), Kostov et al. (1988), Taris (1987), Tsanov et al. (1990, 1992), Broshtilov et al. (2003), Broshtilov and Broshtilova (2007a,b), Kalmukov (2007), and Popov (2009).

The present paper attempts to analyze and assess the results derived from the established intensive plantations for the accelerated production of deciduous and conifer timber in the lowland forest zone of Central North Bulgaria.

## Material and Methods

Field studies began in the vicinity of the village of Paisiy in 1982. Indigenous forest of Turkey oak (*Quercus cerris* L.) and Pubescent oak (*Quercus pubescens* Willd.) has been cut and part of the stand uprooted. Complete soil preparation was performed. In the spring of 1984 the first plantations were established: pure plantations of *Pseudotsuga menziesii* with row widths of 2.4 and 3.6 m and four planting densities – 1.2, 1.8, 2.4 and 3.6 m. Each plot was 0.1 ha and the plantations were established in three different locations. The other plantations were: pure plantations of *Quercus rubra* with initial density of 2.4 x 1.2 m and 3.6 x 1.8 m; a pure plantation of *Tilia tomentosa*, with initial density of 2.4 x 1.2 m; and a cultivar-selection experiment with 14 clones of *Robinia pseudoacacia* with initial planting density 4 x 4 m. In 1985, a pure plantation of *Cedrus atlantica* was established with the same row widths and densities as in plantations of *Pseudotsuga menziesii.* Mixed plantations of *Cedrus atlantica* and *Quercus rubra* and *Tilia tomentosa*, varied sequentially at every other row with initial planting density of 3.6 x 1.8 m were also established. The cultivar-selection experiment with *Robinia pseudoacacia* L. was extended with 14 more clones. The plantations of *Pseudotsuga menziesii* were planted using 2-year-old saplings, while the plantations of *Quercus rubra* and *Tilia tomentosa* were planted using 1-year-old saplings. The cultivar-selection experiment with *Robinia pseudoacacia* L. was established with one-year-old vegetative saplings from root cuttings. After planting the trees were stump-cut and subsequently one shoot was left for each plant. The Cedar plantations were established using 2-year-old saplings of Atlantic and Himalayan cedar (*Cedrus deodara* G. Don). The rows were earthed-up during the first four years, and the inter-row spaces were disc-harrowed three times a year for the first six years.

Measurements were done in 2005. Diameters were measured to nearest 1 cm, and height to nearest 0.5 m. Model trees of Douglas fir, Atlantic cedar, Red oak, Silver lime, and Black locust were extracted for trunk analysis. Results were compared to those of the indigenous Oak forest, local black locust stands, and Austrian Black pine stands.

## Results and Discussion

The comparative analyses of stands of approximately the same age and location enabled certain inferences regarding the specific biological characteristics of the species, and the importance of the initial planting density on their status, growth and increment.

The initial planting density had little impact on the degree of tree loss at the age of 21. Self-thinning was affected to a greater extent by the spacing between the saplings within a row, rather than by the spacing between rows. At density

2.4 and 3.6 m, the increase of spacing between the saplings within a row from 1.2 to 3.6 m expressed the same trend of substantial decreasing the number of fallen and dead saplings. At the age of 21, the percentage of viable trees varied from 70 to 91.7 % (Table 1). Obviously, using a spacing of 1.8 m between the saplings resulted in greater number of survived trees. To a certain extent this could be due that at such spacing the crowns close later and individual trees are less affected by competition of surrounding trees than those planted at initial density of 1.2 m. Conversely, when the growth space was more than 2.4 m, any loss could be attributed to rooting failure and damage caused by wild animals. Douglas fir suffered from debarking and stem cutting by stag and deer, which was observed in other introduced species. This damage could not be prevented, even when stands were fenced. There was rarely more than one stem of Douglas fir at a single planting spot. Growth space had stronger impact on the diameter- than on height growth (Table 1).

The stands with greatest number of trees had the smallest average diameter of 14 cm (planting density 2.4 x 1.2 m, 2546 trees·ha$^{-1}$, with a growth space of 3.93 m$^2$). The smallest diameter was 5.0 and the greatest one was 23 cm. Trees with trunks below the average diameter were predominant. With the increase of growth space, the average diameter of trees in stands with different initial densities also increased. The greater distance between rows provided better growth conditions. When the growth space was above 7.0 m$^2$, the diameter growth was affected to a lesser extent. The height growth depended on the initial density to a lesser extent. At 3.6 x 1.8 m planting density the average height was 13.2 m, while at 2.4 x 2.4 m it was 12.9 m. Regardless of the initial density, trees in all stands were in equally good health, with trunks not self-pruned and branches along the whole stem preserved. The initial planting den-

**Table 1. Growth and yield of 21-year-old stands of Douglas fir at various initial densities**

| Planting density, m | No trees planted, ha$^{-1}$ | Live trees, ha$^{-1}$ | Survival, % | Diameter, cm | | | Height, m | | Stock, m$^3$·ha$^{-1}$ debarked |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Average | Min | Max | Average | max | |
| 2.4 x 1.2 | 3472 | 2546 | 73 | 14.0 | 5.0 | 23.0 | 13.1 | 16.1 | 217.0 |
| 2.4 x 1.8 | 2315 | 2046 | 88 | 15.6 | 6.0 | 23.0 | 13.0 | 16.0 | 228.0 |
| 2.4 x 2.4 | 1736 | 1428 | 82 | 18.3 | 6.0 | 25.0 | 12.9 | 15.6 | 199.0 |
| 2.4 x 3.6 | 1157 | 1008 | 87 | 19.3 | 7.0 | 26.0 | 12.9 | 15.4 | 191.0 |
| 3.6 x 1.2 | 2315 | 1848 | 80 | 16.0 | 6.0 | 23.0 | 13.1 | 16.1 | 216.0 |
| 3.6 x 1.8 | 1543 | 1471 | 95 | 17.6 | 6.0 | 25.0 | 13.2 | 15.6 | 195.6 |
| 3.6 x 2.4 | 1157 | 1068 | 92 | 20.0 | 6.0 | 25.0 | 12.9 | 15.4 | 204.0 |
| 3.6 x 3.6 | 772 | 743 | 96 | 20.3 | 7.0 | 28.0 | 12.9 | 15.3 | 138.0 |

sity has affected only the thickness and length of the branches and the height to which they were withered. The increase of growth space from 2.4 x 1.2 to 3.6 x 3.6 m produced an increase of the percentage of live branches. At the smallest growth space the withered branches were up to 6 or 7 meters, while at the largest growth space they were up to 2 to 4 meters. The volume was dependent on the initial planting density. At planting density 2.4 x 1.2 m debarked volume was 217 $m^3 \cdot ha^{-1}$, and at 3.6 x 3.6 m it was 138 $m^3 \cdot ha^{-1}$, which is relatively high value for this age.

Height growth of the average model tree was most intensive at the age 10 or 11 and the average increment remained high. The diameter growth was most intensive at the age of 13 or 14 in the stands with initial planting density 2.4 x 2.4 m. Although passed the peak, the diameter growth was still intensive. Annual increment values were more than 0.5 cm. Volume growth was intensive and still had not peaked. At the age of 21, Douglas fir trees were still growing intensively with increasing stem volume. The number of withered trees was insignificant – these were trees with a small diameter, considered industrially unimportant. They could be left onsite in order to improve growth conditions. All stands were in good health and unaffected by diseases or pests.

Under the same conditions and initial planting density patterns, Atlantic cedar at the age of 21 displayed less vigorous growth than Douglas fir. The percentage of live trees varied from 50% at 2.4 x 1.2 m planting density to 64% at 3.6 x 1.8 m (Table 2). The degree of self-thinning was also affected by the percentage of Himalayan cedar trees in the stand. The experiment corroborated the opinion that the Himalayan cedar should not be used in North Bulgaria. It is strongly susceptible to shortages of air moisture and low ambient temperatures. The Atlantic cedar showed better adaptability. Another

**Table 2. Growth and increment of 20-year-old stands of Atlas cedar planted in the vicinity of the village of Paisiy at various initial densities.**

| Planting density, m | No trees, $ha^{-1}$ | Live trees, $ha^{-1}$ | Survival, % | Diameter, cm | | | Height, m | | Stock, $m^3 \cdot ha^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | average | Min | Max | average | max | |
| 2.4 x 1.2 | 3472 | 1737 | 50 | 16.3 | 6.0 | 25 | 13.0 | 15.4 | 188.81 |
| 2.4 x 1.8 | 2315 | 1343 | 58 | 16.6 | 7.0 | 28 | 13.0 | 15.2 | 146.0 |
| 2.4 x 2.4 | 1736 | 972 | 56 | 19.3 | 7.0 | 28 | 12.8 | 15.0 | 167.0 |
| 2.4 x 3.6 | 1157 | 640 | 55 | 20.6 | 8.0 | 32 | 12.8 | 15.0 | 112.0 |
| 3.6 x 1.2 | 2315 | 1273 | 55 | 17.0 | 5.0 | 27 | 13.0 | 15.3 | 145.0 |
| 3.6 x 1.8 | 1543 | 1033 | 67 | 19.5 | 8.0 | 31 | 12.9 | 15.2 | 174.0 |
| 3.6 x 2.4 | 1157 | 822 | 71 | 23 | 7.0 | 31 | 12.8 | 15.0 | 167.0 |
| 3.6 x 3.6 | 772 | 361 | 47 | 23 | 13.0 | 34 | 12.7 | 14.9 | 76.0 |

cause for greater self-thinning of stands with greater growth space was the damage inflicted by wild animals. At the age of 21 the stand with initial density 2.4 x 1.2 m had 1,737 remaining trees per hectare with growth space of 5.76 $m^2$ per tree. The stand with greatest initial density of 3.6 x 3.6 m had 361 remaining trees per hectare with growth space of 27.7 $m^2$, which corresponds to the 3.6 x 7.69 m planting density. The increase in growth space resulted in trees with larger diameters.

The stand with initial density of 2.4 x 1.2 m had an average diameter 16.3 cm, with the largest value being 25 cm. Using the same row spacing but greater spacing between the saplings provided better conditions for diameter growth. At 2.4 x 3.6 m planting density the average diameter was 20.6 cm, with the largest one being 32 cm. The same trend was observed for the stand with a row spacing of 3.6 m – the increase of spacing between the saplings resulted in larger diameters (Table 2). At 3.6 x 1.2 m planting density the average diameter was 17 cm, and at 3.6 x 3.6 m it was 23 cm. The same model was observed for the maximum diameter measured in these stands – it was greatest (34 cm) in the stand with the greatest growth space. At the age of 20 the average height of trees was approximately 12 to 13 m, and the maximum one was 15 to 16 m.

The growing stock depends on the number of trees. It is higher when more trees per hectare are retained. At this age the stock of the stands with highest initial density of 2.4 x 1.2 m was 188.81 $m^3 \cdot ha^{-1}$ debarked, but stems were smaller in size. At 2.4 x 1.8 m planting density the stock was 146 $m^3 \cdot ha^{-1}$, and at 3.6 x 1.2 it was 145 $m^3 \cdot ha^{-1}$, but these trees had larger diameters.

Under the same conditions and at the same age, the number of the remaining Cedar trees in the mixed stands depended on the other species. In the stands with Red oak the remaining cedar trees were 21 % more than the trees in the stands with Silver lime (Table 3). Red oak turned out to be a better companion for the Cedar where survival rate was 63.47 % for the Cedar and 84.59 % for the Red oak. Although rare, some Cedar trees had two stems thus reducing their growth space to 9.03 $m^2$. The remaining Cedar trees amounted to 554 trees per hectare. Number of trees having two stems was higher in Red oak, thus reducing the growth space from 7.66 $m^2$ to 5.85 $m^2$. In the mixed stands of Cedar and Silver lime, less than one half of the planted Cedar saplings survived – 363 trees per hectare.

Approximately 94.95 % of the initial Silver lime trees survived. At the same time the number of stems per tree varied from 1 to 6, or total of 2,522 trees per hectare, which is more than three times the amount of initial saplings. Their growth space had shrunk to 3.97 $m^2$ per stem. The Red oak had a better influence on the Cedar than did Silver lime. The greater number of remaining trees per hectare affected their diameter growth – more trees had remained but with smaller diameters. The average diameter of Cedar was 18 cm and the largest one – 25 cm. In the mixed stands with Silver lime less trees survived, but their average diameter was larger – 18.5 cm. The stock of the cedar in the stand with Red oak was 60.32 $m^3 \cdot ha^{-1}$ and in the stand with Silver lime it was 39.46 $m^3 \cdot ha^{-1}$. Silver lime had the smallest average diameter – 11.5 cm, but the greater number of stems resulted in a greater volume – 87.00 $m^3 \cdot ha^{-1}$. Higher stock of the mixed stand of red oak and cedar (134.32 $m^3 \cdot ha^{-1}$) was due to the larger Cedar volume (Table 3). The two accompanying species – Red oak and Silver lime – did not have a significant influence on self-pruning of the cedar. Branches were preserved even in the lowest part of the trunks at height 1.0–1.5 m. Up to one-third of the Red oak trunks were self-pruned, while less than one-third of the Silver lime trunks were self-pruned. Red oak and Silver lime trees were fruit-bearing, in good health and still growing in both diameter and height.

At the age of 21 the pure stands of Red oak were self-thinned to a differing extent depending on their initial density. At 2.4 x 1.2 m planting density about 46 % of the initial saplings survived, while at 3.6 x 1.2 m this percentage was 70 %. The greater growth space facilitates survival of more stems. Although rare, there were some cases of two stems in a single planting spot. Greater initial density had a negative impact on the stands and resulted in a greater number of withered trees. Despite the relatively small number of remaining trees, the greater initial planting density had negatively affected their diameter growth. Trees in the denser pattern had smaller average diameter – 13 cm (Table 3). The experiment proved the theory that the Red oak is a light-demanding species prone to phototropism. The larger initial growth space had a positive effect on the number of remaining trees as well as on better growth and increment. The average trunk diameter was 14 cm and the largest one was 19 cm. The growing stock (debarked) was 146 $m^3 \cdot ha^{-1}$. Under the same conditions Silver lime, being less sensitive to light conditions, had more remaining trees per hectare and more stems per planting spot even in the stand with the highest initial density – 2.4 x 1.2 m (Table 3). As larger number of trees remained, this facilitated the self-pruning, but at certain stage of tree development it negatively affected their diameter growth. With an average diameter of the stand 10.5 cm, debarked volume stock of 180.5 $m^3 \cdot ha^{-1}$ and 212 $m^3 \cdot ha^{-1}$ with bark this sylvicultural system seems to be the most productive among all deciduous tree species.

In Black locust the initial planting density and origin of saplings had a strong influence on the degree of self-thinning. Mixed indigenous stand with initial density of 2.0 x 1.0 m had higher degree of self-thinning and at the age of 15 the survival rate was only 59 %. Average diameter was 10 cm and the largest one in the stand – 22 cm. Number of withered trees in the stand established by using vegetative saplings of selected clones planted at initial density of 4 x 4 m was insignificant. Average diameter of the stand was 21.6 cm and the largest one was 34 cm. The volume stock of the denser stand was smaller – 98 $m^3 \cdot ha^{-1}$, while the stock volume of the stand with a larger growth space was 165 $m^3$ per ha (Table 3). The logs produced by selected clones were larger. Stems were relatively well self-pruned, straight and provided a better assortment with a larger percentage of valuable wood. Under the same conditions Black pine stand had volume stock of 198 $m^3 \cdot ha^{-1}$.

At the same locations indigenous forest consisting mainly of Turkey oak (*Quercus cerris*) of coppice origin had volume stock 120 $m^3 \cdot ha^{-1}$ at the age 25 (Table 3). Both Turkey and Pubescent oak trees had small average diameters of 12 cm, while the one was in some cases more than 20 cm. Most stems were not straight and could only be used for firewood, chemical processing, and (a small amount) as construction material.

**Table 3. Growth and yield of some tree species in the vicinity of the village of Paisiy.**

| Plot No | Tree species | Pattern, m | Density, $ha^{-1}$ | Live trees, $ha^{-1}$ | Survival, % | Age, years | Diameter, cm | | | Height, m | | Stock, $m^3 \cdot ha^{-1}$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | average | min | max | average | max | debarked | with bark |
| 1 | *Quercus rubra* | 2.4 x 1.2 | 3472 | 1597 | 46,0 | 21 | 13 | 6 | 16 | 13.80 | 15.6 | 138.20 | 154.70 |
| 2 | *Quercus rubra* | 3.6 x 1.8 | 1543 | 1305 | 84,6 | 20 | 14 | 6 | 25 | 14.00 | 16.00 | 74.10 | 83.00 |
| | *Cedrus atlantica* | 3.6 x 1.8 | 1543 | 979 | 63,5 | 20 | 18 | 7 | 25 | 13.00 | 15.00 | 60.22 | 67.26 |
| | Total | | | | | | | | | | | 134.32 | 150.26 |
| 3 | *Tilia tomentosa* | 3.6 x 1.8 | 1543 | 1465 | 95,0 | 20 | 11.5 | 6 | 21 | 11.8 | 15.00 | 87.00 | 102.10 |
| | *Cedrus atlantica* | 3.6 x 1.8 | 1543 | 648 | 42,0 | 20 | 18.5 | 6 | 24 | 13.60 | 14.80 | 39.46 | 44.07 |
| | Total | | | | | | | | | | | 126.30 | 146.17 |
| 4 | *R. pseudoacacia* | 2.0 x 1.0 | 5000 | 2950 | 59,0 | 15 | 10 | 6 | 22 | 12.00 | 14.50 | 88.20 | 98.00 |
| 5 | *R. pseudoacacia* | 4.0 x 4.0 | 625 | 619 | 99,0 | 20 | 21.6 | 14 | 34 | 18.00 | 21.5 | 139.00 | 165.00 |
| 6 | *Tilia tomentosa* | 2.0 x 1.2 | 4167 | 2515 | 72,4 | 21 | 10.5 | 4 | 18 | 11.60 | 14.20 | 180.50 | 212.00 |
| 7 | *Pinus nigra* | 2.0 x 2.0 | 2500 | 2015 | 80,6 | 20 | 16 | 8 | 24 | 10.00 | 13.00 | 170.30 | 198.00 |
| 8 | *Quercus cerris 80 %* | Natural | 1371 | | | 25 | 12 | 6 | 20 | 13.00 | 15.40 | 82.60 | 96.00 |
| | *Quercus frainetto 20 %* | Coppice forest | 348 | | | 25 | 12 | 6 | 20 | 13.00 | 15.00 | 20.60 | 24.00 |
| | Total | | | | | | | | | | | 103.20 | 120.00 |

Comparing the stock and quality of timber from plantation with these of indigenous forest showed that cultivated plantations are far more productive.

## Conclusions

The initial planting densities of 2.4 x 1.8 m and 3.6 x 1.8 m for plantations of Douglas fir and Atlantic cedar facilitate survival of larger numbers of trees and provide better growth conditions and therefore, higher growing stock during the first 15 to 20 years after planting. Regular thinning is necessary for production of more valuable stems.

Planting density schemes with greater spacing between the rows – 3.6 or 4.0 m – should be used in the establishment of intensive forest plantations. Both deciduous and coniferous species are suitable for intensive plantations in the lower forest belt (up to 600 m a. s. l.). Suitable coniferous species are Austrian Black pine and Douglas fir. Atlantic cedar could also be used but only under suitable environmental conditions. Of deciduous species Black locust, Red oak and Silver lime could be recommended.

Denser initial planting patterns do not cause sufficient self-pruning of coniferous species. In order to produce knot-free timber these stands should be additionally pruned.

Initial planting density affects the growth and the stock of Black locust. Increasing the growth space from 2 to 16 m$^2$ per sapling stimulates its diameter growth.

The intensive forest plantations at the age of 20 or 21 have two to three times higher growing stock than the indigenous forest stands.

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