Silva Fennica 1993, Vol. 27 N:o 1: 21–28

Influence of initial spacing and planting design on the development of young Scots pine (*Pinus sylvestris* L.) stands

Hannu Salminen & Martti Varmola

TIIVISTELMÄ: ISTUTUSTIHEYDEN JA -KUVIOINNIN VAIKUTUS MÄNTYTAIMIKOIDEN KEHITYKSEEN

Salminen, H. & Varmola M. 1993. Influence of initial spacing and planting design on the development of young Scot pine (*Pinus sylvestris* L.) stands. Tiivistelmä: Istutustiheyden ja -kuvioinnin vaikutus mäntytaimikoiden kehitykseen. Silva Fennica 27(1): 21–28.

Three Scots pine (*Pinus sylvestris* L.) plantations carrying 35 plots with initial spacings from 800 to 5000 plants/ha were studied. Planting designs varied from a square to a rectangle with 5-metre row distance, the plant-to-plant distance being 0.8 metres. At current dominant height of 6 m, rectangularity had no effect on height, diameter, or volume growth of the trees. Slight ovality of stems was observed in rectangular plots but the differences in the cross-wise mean diameters were very small, not over 1.1 mm in terms of plotwise means. The diameter of the thickest living branch of a tree was linearly dependent on the dbh. The branches were clearly thicker between the planting rows at under 1600 stems/ha stand density. A non-square planting pattern is a conceivable alternative when the line corridors suitable for mechanized silvicultural operations are preferred.

Tutkimuksen tavoitteena oli tutkia istuttamalla perustettujen männiköiden kehitystä sekä vaihtelevan istutuskuvioinnin ja tiheyden vaikutusta puiden epäpyöreyteen ja kasvuun. Istutuskuvio, jossa taimet olivat lähellä toisiaan ja taimirivit etäällä toisistaan, ei johtanut riukuvaiheen metsikössä havaittaviin tuotoseroihin. Keskeisimmät runkotilavuutta ja järeyttä kuvaavat puustotunnukset vaihtelivat pääosin runkoluvun mukaan, mutta puiden pituuskehitys ei riippunut istutustiheydestä. Rivi-istutuksessa taimirivin suuntaan mitatut puiden rinnankorkeusläpimitat olivat pienempiä kuin taimirivin vastaiset. Runkojen havaitut epäpyöreydet olivat käytetyn mittaustarkkuuden rajoilla, mutta kuitenkin tilastollisesti merkitseviä. Rivi-istutuksessa oksat kasvoivat paksummiksi vapaan kasvutilan suuntaan, mutta niiden maksimiläpimitat olivat samaa luokkaa tai hieman pienempiä kuin vastaavassa tasavälisessä istutusmuodossa.

Keywords: Scots pine, spacing, yield, quality.
FDC 232.4 + 56

Authors' address: The Finnish Forest Research Institute, Rovaniemi Research Station, P.O. Box 16, FIN-96301 Rovaniemi, Finland.

Accepted June 4, 1993

1 Introduction

Artificial regeneration makes it possible to regulate the growing space of forest trees. A more or less even spacing is generally preferred. However, even in normal planting, the plant-to-plant distances within the rows are frequently shorter than the row-to-row distances. On ploughed areas it is common for the two plant rows in the shoulders of the furrows to be close to each other, while a distance between adjacent furrows may be up to 5 metres.

In rectangular planting (i.e. the distance between the planting rows exceeds the distance between the plants in one row), the number of technical advantages thus achieved is at its best when using one or two-row planting (Lindman et al. 1985). The distance between two adjacent rows must be wide enough for machines to move therein.

The possibilities of using rectangular planting design vary according to soil characteristics, site, and silvicultural regime. Topographically even and fairly fertile sites are most appropriate as the fertile sites require repeated silvicultural treatments such as cleanings. The terrain needs to be fairly even to allow the use of machines.

It has been pointed out that the rectangular planting design would result in a lower total production because the competition between the trees in a row begins earlier and because the entire growth space is not used effeciently (see Lindman et al. 1985). The stems and crowns become asymmetric and the branches thicken in the direction of the free space. According to Dippel (1982), eccentricity of stem cross-sections in unsquare planted Norway spruce (*Picea abies*) stands was more frequent in using wider spacing, though this feature was not found to be prominent. Handler and Jakobsen (1986) did not, however, find asymmetric stems in unsquare planted Norway spruce stands when the dominant tree height was approximately 10 metres. Daniels and Schultz (1975) using *Pinus patula*, and Kramer et al. (1971) using Norway spruce concluded that the prevailing winds have a greater effect on the ovality of stems than the rectangular planting patterns. Isomäki (1986) found that the trees along the edge of line corridors grew slightly elliptical in cross-section at breast height, but the effect was less pronounced in Scots pine stands than in Norway spruce stands. Handler and Jakobsen (1986) (with Norway spruce) and Elfving (1975) (with Scots pine) reported that branches grew thicker in the direction of the plant rows. Dippel (1982) concluded that the rectangular spacing of Scots pine caused a slight decrease in the mean maximum branch diameter in the third whorl from the top.

Risk of damage may be higher in rectangular spacing. Asymmetric crowns, a short plant-to-plant distance, and the winds along the rows tend to cause snow damage. Short plant-to-plant distances increase the likelihood of severe local damage, such as needle cast.

The object of this study was to find out whether the rectangular planting design exerts any effect on the roundness of stems and on the branch thickness, and what impact the planting design (square versus rectangular) and the initial spacing have on the stand characteristics.

2 Material and methods

2.1 Experimental stands

The material consists of plantations on three experimental areas. Areas 1 and 2 are situated in Kuru in southern Finland (latitude 62°02', longitude 23°44') and area 3 in Muhos in central Finland (latitude 64°53', longitude 26°05'). The elevation is 160 m (above sea level) for areas 1 and 2, and 60 m for area 3. The respective mean annual temperature sums are 1200 and 960 d.d. The areas 1 and 2 were estimated to be stony *Vaccinium* site type (Cajander 1949). Area 3 was former agricultural land.

On areas 1 and 2, clearcutting was carried out in 1970–71, and the sites were ploughed in 1971 and planted in 1972 with 3 year-old (1G+2F, G = greenhouse, F = field) bare-rooted plants, origin unknown. The former agricultural land (area 3) had been ploughed using agricultural implements and planted in 1974 with 2 year-old (1G+1F) bare-rooted plants, origin 50 km south of area 3. Mechanical weed control was carried out in the autumn of 1974.

2.2 Planting designs

Five different initial spacings were used: 800, 1100, 1600, 2500, and 5000 plants/ha. Each spacing included a square planting design (rectangularity 1:1), an alternative with a row distance of 3.5 metres (rectangularity from 1:1.3 to 1:3.3) (except for area 3), and an alternative with a 5.0 metre row distance (rectangularity from 1:2 to 1:6.3) (Table 1). In the case of 800 plants/ha, a planting design with a row distance of 8 metres was also applied (rectangularity 1:5.2). In the spacing of 5000 plants/ha, only the square alternative was used.

Each area comprised only one block without replications. When planting area 3, the alternative of 3.5 meter row distance was omitted. The total number of plots was 35, each plot at least about 0.25 ha in area.

Table 1. Initial spacings and planting designs of experimental areas.

Initial spacing, trees/ha	Square spacing	Rectangular spacing		
	Planting design, m (row-to-row distance and plant-to-plant distance)			
800	3.5 × 3.5	5.0 × 2.45	8.0 × 1.53	
1100	3.0 × 3.0	3.5 × 2.6	5.0 × 1.8	
1600	2.5 × 2.5	3.5 × 1.8	5.0 × 1.25	
2500	2.0 × 2.0	3.5 × 1.15	5.0 × 0.8	
5000	1.4 × 1.4			

2.3 Measurements

Mortality was inventoried six years after the planting (in 1978) in areas 1 and 2. The inventory covered the entire area. In 1986, a smaller sample plot was marked out inside the area. If high mortality was observed in a certain part of the whole area, said part was omitted. In all cases the outermost plant rows were excluded from the sample plot in order to avoid the edge effect of the neighbouring plots.

The measurements were carried out in 1986 when areas 1 and 2 were of the age of 17 years and area 3 of the age of 14 years (Table 2). Dbh's across and within the row were measured on all trees (Fig. 1). The technical quality of the stems and the state of health of the trees were estimated using ocular classification. The quality was described using classes normal, branchy, crooked, forked, branchy & crooked, branchy & forked, crooked & forked, branchy & crooked & forked, or broken stem. State of health was classified into healthy, dead, diseased or damaged, top dry, top dry & dying, or dying trees. Mortality was counted. Sample trees were selected systematically. At least 50 sample trees per sample plot were measured. The following variables were measured on the sample trees: dbh and diameter at the height of 3.5 meter across and within the

Table 2. Minimum, maximum and mean values of stand parameters in 1986.

Number of area Location	1 Kuru	2 Kuru	3 Muhos
Age, a	17	17	14
Mean height, m	4.8–5.3 (5.0)	4.2–5.4 (5.0)	4.0–4.7 (4.4)
Dominant height, m	5.6–6.6 (6.1)	5.6–7.0 (6.1)	4.7–5.6 (5.1)
Mean diameter, cm	6.8–9.5 (8.4)	5.4–9.4 (7.8)	6.7–9.1 (7.9)
Basal area, m^2/ha	5.3–20.2 (9.8)	3.0–11.5 (7.3)	4.3–15.1 (7.9)
Stem volume, m^3/ha	17.7–68.0 (33.4)	9.8–39.4 (25.0)	13.0–45.4 (24.3)
Number of trees/ha	804–5000 (1814)	732–3320 (1516)	789–4019 (1654)

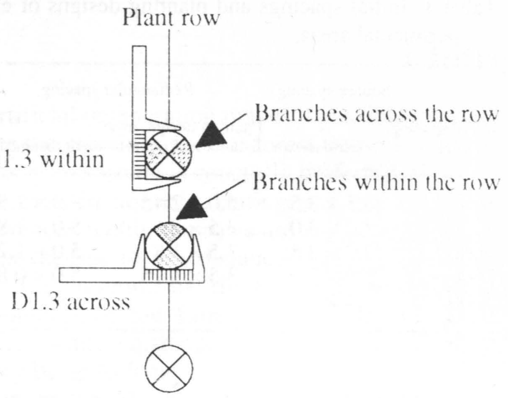

Fig. 1. Diameter measurements across and between rows.

row, the diameter and location of the thickest living branch across and within the row, the diameter of the thickest dry branch across and within the row (Fig. 1) tree height, 5-year height increment, crown height, and crookedness. The 5-year height increment above 2.5 metres from five dominant trees was measured according to Hägglund's (1976) intercept-method in order to estimate the site indexes.

The site index variation between the three experimental stands was small. Using Hägglund's (1976) model, the standwise means for H100 were 23.4–23.8. The site indexes corresponded to a better *Vaccinium* site type (see Vuokila and Väliaho 1980). Compared to young Scots pine stand models (Varmola 1987), the development in the experimental stands was estimated to be slightly faster than that indicated by site index H100 = 24.

2.4. Methods

The mean values of a stand characteristic from individual sample plots were used as an input for a statistical analysis. Technical quality and state of health were described fitting a log-linear model to the tables of contingent (see Habermann 1973). Mortality was analysed using a stepwise logistic regression model (see Häkkinen and Linnilä 1987). Variables measured using the ratio scale were analysed with ANOVA. The ANOVA-model had the form:

$$Y_{ijk} = \mu + A_i + R_j + D_k + DR_{jk} + \varepsilon_{ijk} \quad (1)$$

where

Y = dependent variable
μ = overall mean
A = area effect (i = 1,2,3 corresponding to stands 1,2 and 3)
R = rectangularity effect (j = 1,2,3 corresponding to classified rectangularities 1:1, 1:2 and 1:3–6)
D = spacing effect (k = 1,2,3,4,5 corresponding to densities 800, 1100, 1600, 2500 and 5000 plants/ha)
ε = error

Branchiness was analysed by means of regression analysis using data on individual sample trees. The diameter of the thickest branch was modelled using dbh as an independent variable, and the planting density, rectangularity classes and experimental stand as dummy-variables (see Draper and Smith 1966).

3 Results

3.1 Stand characteristics

The average mortality, inventoried 6 years after the planting in 1978 over the entire areas, was 10–12 % in areas 1 and 2. The mortality was not dependent on spacing. In 1986, the mortality per cent varied from 4 % to 34 % when measured on sample plots (n = 35). According to stepwise logistic regression analysis, rectangularity or spacing did not have a statistically significant effect on tree plant mortality.

Neither planting design nor density did have any effect on height development of the trees. In the most sparse spacings (800 plants/ha), the tree height was slightly less than in the other spacings. According to ANOVA, differences could be found only between the areas ($P < 0.01$) regarding both the mean and the dominant height. In area 2 the mean height growth reduction had been caused by damage. The planting design did not have any effect on the mean diameter of the trees. On the other hand, as can be expected, the effect of spacing was significant ($P < 0.01$). In the basal area, the differences between the spacings were even greater. The planting design did not have any effect on volume development.

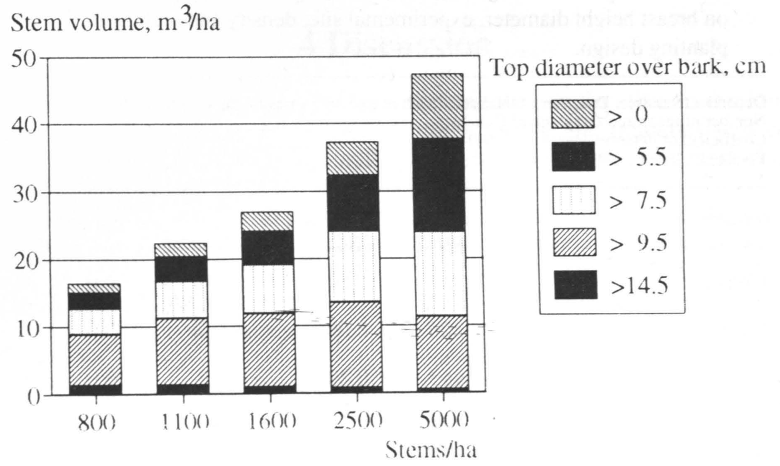

Fig. 2. Stem volume in over bark top diameter classes with respect to planting density.

According to ANOVA, spacing had a statistically significant effect on stand volume ($P < 0.01$). Increased stem volume was mainly a result of the increased number of small-dimension trees (Fig. 2). The amount of timber with overbark diameter of over 9.5 cm was approximately the same in all spacings.

3.2 Tree parameters

The asymmetry of stems was described as the ratio of sample plot averages between tree diameters across and within the rows of trees (n = 35) (Fig. 1). The ratios differed between both the experimental stands ($P < 0.01$) and the rectangularity classes ($P < 0.01$) with statistical difference. An interaction could be seen in rectangularity * spacing ($P < 0.1$). However, the differences between tree diameters were small. The difference in plotwise counted average of tree diameters was at its highest 1.1 mm with a spacing of 5.0 × 0.8 metres. Rectangularity had led to some asymmetry of stems, though at pole stage the asymmetry was still rather inconspicuous.

Branchiness was analysed on single tree observations (n = 1621). The diameter of the thickest living branch of trees was linearly dependent on the dbh. In the regression model, the planting density and rectangularity classes were significant dummy-variables (Table 3). The effect of the initial spacing on branch diameters was observed both across and within the plant rows. The mean branch thickness was a little higher in square planting designs (Table 4). When the dbh increased up to 10 cm at the dominant height of 6 metres, the diameter of the thickest living branch was approximately 30 mm, and the trees are no longer suitable for green pruning.

The branches were thicker across than within the planting rows when an unsquare planting pattern was applied (Fig. 3). The differences were usually small and they did not have any statistical significance. The greatest differences observed were in the lowest spacing treatment where also the greatest dbh's were observed. The maximum difference in the diameter means of the thickest branches was 2.5 mm. When the density in unsquare planting designs was over 1600 stems/ha, no differences could be found between the branch diameters within and across the planting rows.

The thickest branch was usually located approximately at 1.8 metre height, this height being independent of spacing and rectangularity. The thickest dry branches were normally under 15 mm in diameter and they were found in the densest spacings; this was an indicator of more rapid self-pruning.

On the basis of the ocular assessment, the trees regarded as healthy amounted to 89 % of all trees. Most of the dead trees were found in the densest spacings (average 2 %). Most of the dying trees (average 6 %) were found in spacings of 1100, 1600, and 2500 trees/ha. In the regression analysis including the contingent table, no significant correlation between the health of trees and the initial spacing, planting design, or loca-

Table 3. The dependence of the diameter of the thickest living branch of trees on breast height diameter, experimental site, density and rectangularity of planting design.

Dependent variable: Diameter of thickest branch of tree, mm (mean = 26.46, sd = 0.186)
Number of measured sample trees (N): 1618
Coefficient of determination $R^2 = 0.603$
F-value (9.1608) = 270.84

Variable	Coefficient	Std error	T-value	Probability
Constant	7.252	0.627	11.58	100.0
D1.3, cm	0.224	0.006	40.78	100.0
Dummy variables				
Stand/Area1	–1.982	0.298	–6.66	100.0
Stand/Area2	–3.720	0.325	–11.43	100.0
N/800	4.293	0.510	8.42	100.0
N/1100	2.685	0.517	5.20	100.0
N/1600	1.853	0.521	3.56	99.96
N/2500	1.453	0.511	2.84	99.55
SPACING/EQUAL 1:1	1.064	0.276	3.85	99.99
SPACING/RECTAN 1:2	1.234	0.358	3.45	99.94

tion of the experimental area was found. Less than half of all trees were classified as being of normal technical quality. Crookedness was the most common factor decreasing the quality (1/3 of the trees). Over 10 % of the trees were classified as branchy. The regression analysis with the contingent table showed that crookedness was more common in the densest spacings, the worst tree stem quality being in area 2 irrespective of the fact that the technical quality of the stems had not been affected by the planting design.

Table 4. Diameter of the thickest living branch (rectangular planting designs 1:1.3–1:2 were not applied on area 3).

Planting design	Square (1:1)	Rectangle (1:1.3–1:2)	Rectangle (1:2.7–1:6.3)
Trees/ha	Mean diameter of branch, mm		
5000	19.3	-	-
2500	23.2	(22.9)	22.4
1600	24.2	(24.0)	24.7
1100	27.3	(26.3)	24.9
800	28.6	(27.4)	28.0

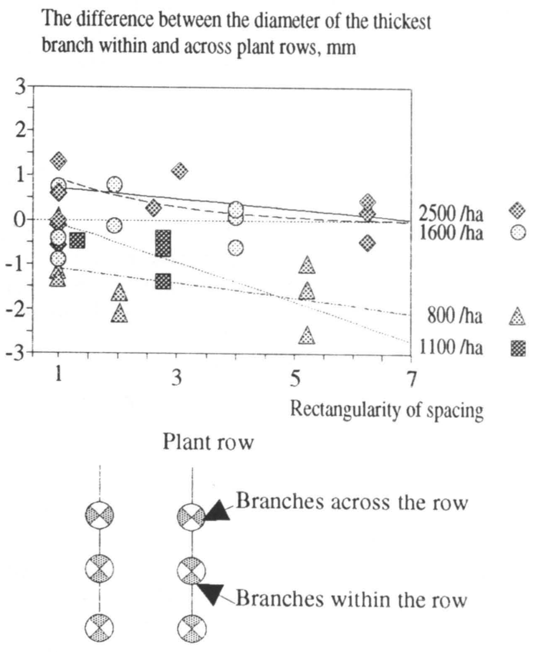

Fig. 3. The difference between diameter of the thickest branch in the crown-sections across and between rows.

4 Discussion

Rectangularity had a noticeable effect on stem asymmetry. There was also a statistically significant difference between the three experimental stands. This was apparently due to area 3 where ploughing had been carried out prior to planting. The potential asymmetry in the root systems may have had an effect on the asymmetry of the stems. As a whole, the asymmetry was minor, at most 1.1 mm, in terms of the difference of plotwise mean diameters.

It is conceivable that when the relative growing space decreases, diametric asymmetry increases, at least in absolute terms. Handler and Jakobsen (1986) found no significant differences of cross-wise diameters in unsquare planted Norway spruce stands after the dominant height exceeded 10 metres. They considered the maximum difference of 3–4 mm to be insignificant. According to Kärkkäinen (1977), asymmetry as a whole is technically considerably less harmful than crookedness.

Besides asymmetry, branchiness also affects the quality of stems. At the time of measurement, the experimental stands were in a rapid branch growth phase. The crown limit was no higher than 1 metre, except in the most dense spacing (5000 stems/ha), and the crown ratio was thus 80–90 %. Because the thickest branches usually remain alive in the lower part of the green crown, the branches will continue growing for a relatively long period on a height of butt log.

Planted Scots pine stands will usually grow branchy compared with artificially seeded or naturally regenerated stands. In the experimental stands, the branch diameters were somewhat larger than those reported in a previous study concerning the whole of Finland (Varmola 1980) where the thickest branch had the mean diameter of 30 mm while the dbh was approximately 12 cm.

So far, the rectangular planting design has had no effect on the stand characteristics, and there is no need to thin stands earlier than usually. Mean height, mean diameter, basal area, and volume were independent of rectangularity. Since rectangularity had not had any effect on the stand characteristics, and only a very small effect on the technical quality of the tree stems, there is no reason not to apply a rectangular planting design.

Acknowledgements: We thank Professor Matti Leikola and docent Heikki Smolander for their constructive reviews and suggestions for improvement.

References

Cajander, A.K. 1949. Metsätyypit ja niiden merkitys. Forest types and their significance. Acta Forestalia Fennica 56. 69 p.

Daniels, F.W. & Schultz, C.J. 1975. Rectangular planting patterns in Pinus Patula stands in the Eastern Transvaal. Forestry in South Africa 16: 61–62.

Dippel, M. 1982. Auswertung einer NELDER-Pflanzverbadsversuchs mit Kiefer im Forstamt Walsrode. Allgemeine Forst und Jagdzeitung, 153. Jahrgang, Heft 8: 137–152.

Draper, N.R. & Smith, H. 1966. Applied regression analysis. John Wiley & Sons, New York. 407 p.

Elfving, B. 1975. Volym och struktur i ogallrade tallbestånd. Skoghögskolan, Institution för skogsproduktion, Rapporter och Uppsatser 33. 128 p.

Haberman, S.J. 1973. Log-linear for contingency tables, algorithm AS 51. Applied Statistics 21: 218–224.

Hägglund, B. 1976. Skattning av höjdboniteten i unga tall- och granbestånd. Summary: Estimating site index in young stands of Scots pine and Norway spruce in Sweden. Skogshögskolan, Institution för skogsproduktion, Rapporter och Uppsatser 39. 66 p.

Häkkinen, R. & Linnilä, K. 1987. Logistiset ja loglineaariset mallit ja niiden ratkaiseminen BMDP-ohjelmistolla. Metsäntutkimuslaitoksen tiedonantoja 279. 47 p.

Handler, M.M. & Jakobsen, B. 1986. Nyere danske planteafstandsforsok med rodgran (Recent Danish spacing experiments with Norway spruce). Det Forstlige Forsogsvaesen I Danmark (The Danish Forest Experiment Station). Beretninger udgivne ved den forstlige forsogskommission. Reports, Bind XXXX, Haefte 4: 359–442.

Isomäki, A. 1986. Linjakäytävän vaikutus reunapuiden kehitykseen. Summary: Effects of line corridors on the development of edge trees. Folia Forestalia

678. 30 p.
Kärkkäinen, M. 1977. Puu, sen rakenne ja ominaisuudet. Helsingin yliopiston monistuspalvelu. 442 p.
Kramer, H., Dong, P.H. & Rusack, H.J. 1971. Untersuchung der Baumqualität in weitständig begründeten Fichtenbeständen. Allgemeine Forst und Jagdzeitung, 142. Jahrgang, Heft 2: 33–46.
Lindman, J., Näslund, B-Å., Olsson, P. & Samuelsson, H. 1985. Radförband. Summary: Rectangular line planting. Ett NSR-projekt redogörelse nr 8. Forskningsstiftelsen Skogsarbeten. 31 p.
Varmola, M. 1980. Männyn istutustaimistojen ulkoinen laatu. Summary: The external quality of pine plantations. Folia Forestalia 451. 21 p.
— 1987. Männyn viljelytaimikoiden kasvumalli. Lisensiaattityö. Helsingin yliopisto, metsänarvioimistieteen laitos. Manuscript.
Vuokila, Y. & Väliaho, H. 1980. Viljeltyjen havumetsiköiden kasvatusmallit. Summary: Growth and yield models for conifer cultures in Finland. Communicationes Instituti Forestales Fenniae 99(2). 271 p.

Total of 16 references