# Influence of Thinning on Spiral Grain in Norway Spruce Grown on Highly Productive Sites in Southern Sweden

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Grain spirality was investigated in eight stands of Norway spruce (*Picea abies* (L.) Karst.) subjected to different thinning regimes. The dominating general pattern of spiral grain found in this study was typical for conifers, with a maximum of left-handed spirality close to the pith, which decreased towards the bark and sometimes changed to right-handed spiral grain in the outer growth rings. However, there was a large amount of between-tree variation in spiral grain. The effect of thinning on grain spirality was investigated by relating annual ring width to spiral grain, since thinning affects growth rate. A positive correlation between ring width and grain angle was found, but a considerable number of trees showed no or a negative correlation. A statistically significant effect of ring width was only found in five of the eight stands. Heavy thinnings, removing 60 % of the basal area of a stand, considerably increased spiral grain, whereas the effects of light thinnings were inconsistent. These results support the findings of earlier studies indicating that spiral grain formation is under considerable genetic control, while its expression can be changed by silvicultural methods which affect growth rate.

**Keywords** grain angle, growth rate, Norway spruce, ring width, spiral grain, thinning
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## 1 Introduction

Spiral grain is considered to be one of the most important wood properties affecting the value of wood products (Northcott 1965). It reduces the strength of the sawn wood (Northcott 1965, Kollmann and Coté 1984) and causes twist during drying (Northcott 1965, Danborg 1994a, 1994b, Perstorper et al. 1995, Forsberg 1997).

Based on the results of several investigations on conifers, it appears that, in general, the slope of spiral grain is usually left handed when the trees are young, but with increasing age the grain straightens out and gradually shifts to the right

(Hartig 1895, Burger 1941, Elliott 1958, Noskowiak 1963, Krempl 1970, Harris 1989, Danborg 1994b, Jensen 1994a). However, in several investigations a large amount of individual variation in the grain angle pattern was found (Hartig 1895, Northcott 1957, Lowery 1966, Krempl 1970, Bues 1990, Koch and Schlieter 1991, Jensen 1994a).

The formation of spiral grain is under considerable genetic control, while its expression may be dependent, at least partly, on factors affecting the growth conditions of trees (Harris 1989). Initial spacing as well as precommercial and commercial thinnings, which affect growth rates, should influence the severity of spiral grain. For Norway spruce in stands grown on fertile sites in Denmark, Danborg (1994b) found that grain angles were larger in fast-growing trees than in slower-growing ones. This was also the case in Sitka spruce (Brazier 1967, Pedini 1990). However, in other investigations on Norway spruce no correlation between ring width and spiral grain was found (Krempl 1970, Bues 1990, Jensen 1994a).

Controversy exists concerning effects of growth rate on spiral grain development, and we do not fully understand the mechanisms responsible for spiral grain formation. Theories developed by Bannan (1966, 1967) and Hejnowicz (1973) relate spiral grain formation to the anticlinal division of cambial cells. Among many types of morphogenetic events that can contribute to the changing orientation of cambial initials, the pseudotransverse division is of major importance.

In addition, there is still controversy as to the function of spiral grain. It has been suggested that spiral grain benefits trees mainly by altering the water and nutrient distributions within the tree (Kubler 1991) and increasing stability in areas with strong prevailing winds (Thunell 1951, Skatter and Kucera 1997).

The purpose of the present study was to determine how an increase in growth rate caused by thinning affects the development of spiral grain in Norway spruce planted on highly productive sites in southern Sweden.

# 2 Material and Methods

## 2.1 Stand Description and Sample Trees

In this investigation stem discs from trees included in three thinning trials in southern Sweden were sampled. These trials are part of a large series of thinning and fertilization experiments. In two of the trials the thinning regimes represented are thinning from below (TB6/20, TB3/40, TB1/70), thinning from above (TA6/20) and natural thinning (T0/0). The first number refers to the number of thinnings planned during the rotation period, and the second refers to the percent of the basal area removed. In Table 1 exact values are presented for basal area removed at thinning on each plot. In contrast to thinning from below, thinning from above is characterized by the removal of the largest trees in a stand.

The trials were set up according to a randomized block design. Each plot (0.1 ha) is surrounded by a 10-m-wide buffer strip which is treated in the same way as the plot itself. The trials included in this investigation are described in Table 2. A more detailed description of the thinning and fertilization experiment is given by Eriksson and Karlsson (1997).

From 135 sample trees, stem discs were taken at 4.0 m height between branch whorls. In trials 682 and 941, all trees removed in the thinnings were sampled. In trial 949 the sampled trees belonged to the final stand and were considered to roughly represent its diameter distribution. In

**Table 1.** Percentage of basal area removed by thinning for trials and thinning regimes.

| Trial | Thinning regime | Thinning | | | |
|---|---|---|---|---|---|
| | | 1st | 2nd | 3rd | 4th |
| 682 | TB6/20 | 26 | 23 | 29 | - |
| 941 | TB6/20 | 0 | 19 | 20 | 23 |
| | TB3/40 | 35 | 0 | 44 | 0 |
| | TA6/20 | 11 | 9 | 21 | 12 |
| 949 | TB6/20 | 34 | 27 | 34 | 26 |
| | TB1/70 | 60 | 0 | 0 | 0 |
| | TA6/20 | 23 | 36 | 31 | 35 |
| | T0/0 | 0 | 0 | 0 | 0 |

**Table 2.** Description of the stands and sample trees.

| | Stand description | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 682 | 941 | | | 949 | | | |
| Latitude | 59°29' | 56°05' | | | 58°40' | | | |
| Total age, years | 52 | 58 | | | 50 | | | |
| Thinning regime | TB6/20 | TB6/20 | TB3/40 | TA6/20 | TB6/20 | TB1/70 | TA6/20 | T0/0 |
| Site index, m * | 31.9 | 31.6 | 34.7 | - | 35.9 | 34.7 | - | 36.5 |
| DBH, mm (arithm.) | 192 | 229 | 308 | 151 | 298 | 267 | 240 | 190 |
| $H_L$ , m ** | 20.1 | 22.2 | 25.7 | 17.8 | 24.4 | 23.3 | 22.9 | 23.3 |
| Stems/ha *** | 4512 | 4458 | 4200 | 4080 | 3330 | 3400 | 3043 | 3100 |
| | Sample trees | | | | | | | |
| No. of sample trees | 22 | 28 | 27 | 21 | 9 | 9 | 9 | 10 |
| DBH, mm (arithm.) | 150 | 197 | 250 | 224 | 285 | 286 | 216 | 197 |
| Mean ring width, mm | 1.65 | 1.84 | 2.56 | 2.21 | 3.39 | 3.55 | 2.56 | 2.44 |
| Mean grain angle, ° | 1.60 | 2.07 | 2.32 | 2.93 | 2.40 | 2.71 | 1.65 | 1.91 |

* Site index is the predicted dominant height (m) at 100 years of age (Hägglund and Lundmark 1981)
** Basal area weighted mean height
*** Before first thinning

all trials sample trees were taken from both the plot itself and from the buffer strip, avoiding edge trees. On all discs from trials 682 and 941, diametrical strips from north to south with a tangential width of 150 mm and a height of 50–100 mm, including the pith, were sawn. From 23 of the stem discs in stand 949, crosses (i.e. two diametrical strips at right angles) were sawn to measure spiral grain in the east-west direction as well. The remaining discs were only sawn into diametrical strips. Strips with knots were excluded from the investigation.

After measuring the annual ring width of the south radius, the spiral grain on each diametrical strip and cross was measured using the method described by Pedini (1990) and Danborg (1994b). On the tangential surface of the samples the slope of grain was marked with 2–4 lines using a scribe instrument. The samples were placed on a base plate in front of the indicator needle which was then adjusted until it was parallel with the marked lines. On a scale spiral grain could be measured with a precision of 0.5°. The sample was then turned so that the grain angle of the opposite side could be measured. The annual rings were removed with a hammer and a chisel or, in the case of the samples from trial 949, by grinding, always exposing the earlywood of a year ring. With the latter method it was easier to expose the exact same area within each year ring for the grain-angle measurement because there might also be some variation within the year ring (Wobst et al. 1994). The measurement was made on every or every second growth ring.

A left-handed slope, i.e. grain running from the lower right corner of the tangential surface towards the upper left corner, was denoted as beeing positive and a right-handed slope, i.e. grain running in the opposite direction, as negative. The mean of two measurements of opposing radii (north–south, east–west) in the same annual ring was calculated to eliminate errors related to skewness originating in the sample preparation (Brazier 1965). Thus, from each diametrical strip one value was obtained for the grain slope of each annual growth ring measured.

## 2.2 Statistics

Statistical analyses were made using the SAS statistical program package ver. 6.11 for personal computers. Due to the different sources of variation the statistical analyses were performed using the *PROC MIXED* procedure (SAS/STAT software... 1996). The use of the *RANDOM* statement in this procedure made it possible to fairly compare values generated from the same tree.

Grain angle data were analyzed stand by stand. Since the treatments were not replicated within the trials, statistical tests could not be used to compare the different thinning regimes. To investigate growth rate effects on spiral grain, a model was used including ring number from bark (RN) and ring width (RW) as fixed effects while the tree (T) was included as a random effect. Ring number was counted from bark inwards instead of from pith outwards to make sure that thinning occurred at the same ring number for all sample trees. Variance components for T and the residuals were estimated using the restricted maximum likelihood (REML) method (SAS/STAT software... 1996). Partial correlation coefficients between grain angle and ring width were computed using the *MANOVA / PRINTE* statement (SAS user's guide... 1985).

# 3 Results

The tangential variation in grain angle within annual growth rings was analyzed in the 23 crosses from trial 949. A consistent radial development in grain angle was found between the two directions (Fig. 1). Differences between both measurements were only found for TB1/70. The correlation between the two measurements for all sample trees was 0.86 (Table 3).

Ring number (RN) had a statistically significant effect ($p < 0.05$) on grain angle in every

**Table 3.** Correlations between the two measurements of grain angle within the same growth ring for the sample trees in trial 949.

| Thinning regime | No. of sample trees | Correlation coefficient |
|---|---|---|
| TB6/20 | 4 | 0.91 |
| TB1/70 | 7 | 0.82 |
| TA6/20 | 6 | 0.83 |
| T0/0 | 6 | 0.88 |

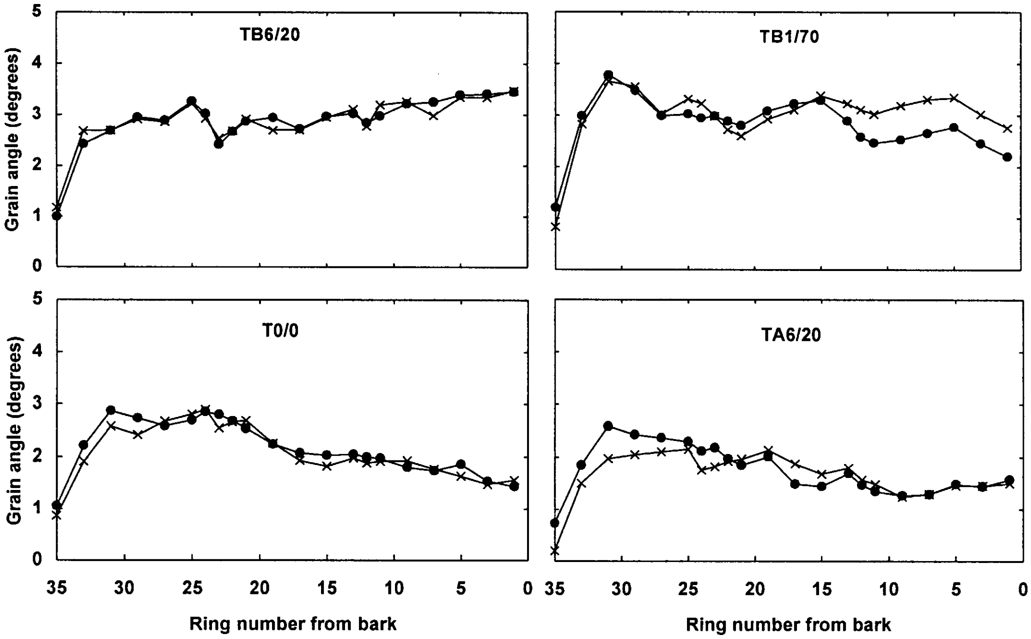

**Fig. 1.** Mean grain angles for the two diametrical strips (● : south–north, × : west–east) in trial 949.

**Table 4.** Test of the dependence of grain angle on ring number from bark (RN) and ring width (RW) in a stand by stand analysis. RW is a covariate while RN is a factorial class variable.

| Trial | | Source | NDF | DDF | Type III F-value | P-value |
|---|---|---|---|---|---|---|
| 682 | TB6/20 | RN | 18 | 333 | 12.81 | 0.0001 |
| | | RW | 1 | 333 | 5.46 | 0.0201 |
| 941 | TB6/20 | RN | 20 | 503 | 11.56 | 0.0001 |
| | | RW | 1 | 503 | 8.73 | 0.0033 |
| | TB3/40 | RN | 21 | 451 | 12.77 | 0.0001 |
| | TA6/20 | RN | 20 | 374 | 9.57 | 0.0001 |
| | | RW | 1 | 374 | 17.29 | 0.0001 |
| 949 | TB6/20 | RN | 21 | 159 | 2.35 | 0.0015 |
| | TB1/70 | RN | 20 | 157 | 4.65 | 0.0001 |
| | | RW | 1 | 157 | 8.18 | 0.0048 |
| | TA6/20 | RN | 20 | 156 | 5.50 | 0.0001 |
| | T0/0 | RN | 21 | 175 | 3.03 | 0.0001 |
| | | RW | 1 | 175 | 13.43 | 0.0003 |

**Table 5.** Estimates of the variance components for the random effects, within trees (residuals) and between trees (T), in a stand by stand analysis from Table 4.

| Trial | | Source | Estimate | Ratio |
|---|---|---|---|---|
| 682 | TB6/20 | T | 0.6165 | 1.6 |
| | | Residual | 0.3940 | 1.0 |
| 941 | TB6/20 | T | 1.1784 | 2.2 |
| | | Residual | 0.5377 | 1.0 |
| | TB3/40 | T | 0.8050 | 1.8 |
| | | Residual | 0.5235 | 1.0 |
| | TA6/20 | T | 1.5458 | 2.9 |
| | | Residual | 0.5387 | 1.0 |
| 949 | TB6/20 | T | 0.8729 | 2.0 |
| | | Residual | 0.4364 | 1.0 |
| | TB1/70 | T | 0.8778 | 2.3 |
| | | Residual | 0.3771 | 1.0 |
| | TA6/20 | T | 0.9169 | 2.5 |
| | | Residual | 0.3691 | 1.0 |
| | T0/0 | T | 1.0136 | 2.2 |
| | | Residual | 0.4663 | 1.0 |

stand, while ring width (RW) only had a significant effect in five of the eight stands (Table 4). The estimates show that the random variation within trees (residuals) is far lower compared with the variation between trees (Table 5). The variation between trees was found to be 1.6 to 2.9 times greater than the variation within trees (Table 5), while the variation in ring width was larger within trees than between them. In 57 % of the sample trees there was a positive correlation between ring width and grain angle, but for the remaining trees the correlation was zero or negative (Table 6).

The general grain-angle pattern was a left-handed spiral grain that reached a maximum angle at the second or third growth ring from pith and then decreased towards the bark (Figs. 2, 3, 4), in some cases followed by right-handed spiral grain in the outer wood. Marked differences from this pattern were observed, especially for thinning regimes TB6/20 and TB1/70 in trial 949 where the grain angle increased again towards the bark after the first thinning (Fig. 4). Thus, there was a large amount of variation in grain angle between trees. In some trees a change-over to right-handed spiral grain occurred after 20–25 growth rings from the bark.

In trial 682 the three thinnings carried out so far did not show any effect on either ring width or spiral grain (Fig. 2). Spiral grain constantly decreased towards the bark. In trial 941 the third thinning resulted in an increase in ring width of about 1.0 mm after heavy thinning from below (TB3/40) and light thinning from above (TA6/

**Table 6.** Numerical distribution of trees classified according to the level of correlation between grain angle and ring width. Number of significant correlations within parentheses.

| Thinning regime | | No. of sample trees | 1–0.6 | 0.59–0.2 | 0.19–(–0.19) | (–0.2)–(–0.59) | (–0.6)–(–1) |
|---|---|---|---|---|---|---|---|
| 682 | TB6/20 | 22 | 3 (3) | 8 (1) | 5 (0) | 2 (1) | 4 (4) |
| 941 | TB6/20 | 28 | 7 (7) | 14 (2) | 4 (0) | 3 (2) | - |
| | TB3/40 | 27 | 4 (4) | 13 (4) | 4 (0) | 3 (1) | - |
| | TA6/20 | 21 | 2 (2) | 7 (4) | 7 (0) | 5 (0) | - |
| 949 | TB6/20 | 9 | - | 6 (2) | 2 (0) | 1 (0) | - |
| | TB1/70 | 9 | 2 (2) | 4 (3) | 3 (0) | - | - |
| | TA6/20 | 9 | 1 (1) | 1 (0) | 3 (0) | 4 (0) | - |
| | T0/0 | 10 | 2 (2) | 4 (2) | 3 (0) | 1 (1) | - |

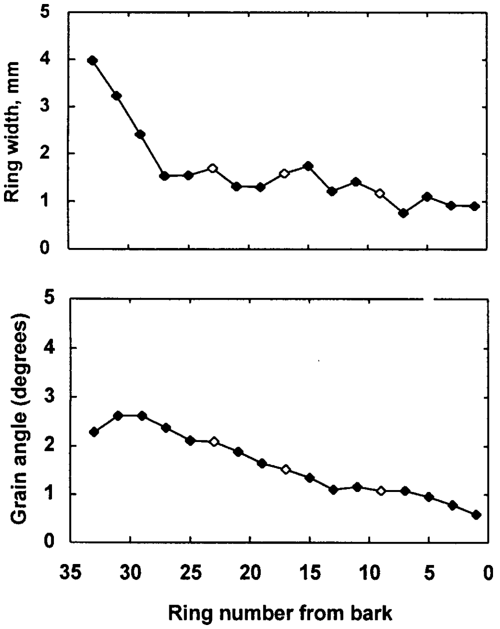

**Fig. 2.** Ring width and spiral grain in trial 682. Thinning regime: TB6/20 (◆). Unfilled breakpoints represent growth rings formed just prior to thinning.

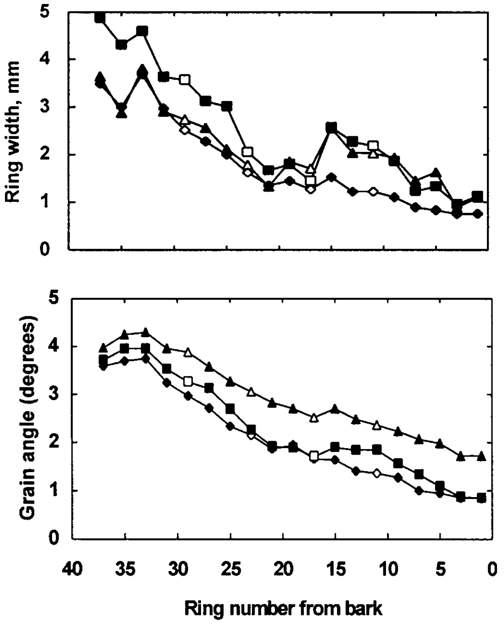

**Fig. 3.** Ring width and grain angle in trial 941. Thinning regimes: TB6/20 (◆), TB3/40 (■),TA6/20 (▲). Unfilled breakpoints represent growth rings formed just prior to thinning.

20) (Fig. 3). Both thinning regimes also resulted in a slight increase in spiral grain. For TB3/40 the increase persisted for 10 years. The other thinnings and thinning regime TB6/20 did not have any effect on spiral grain.

In trial 949 the first and second thinnings affected ring width in all thinning regimes (Fig. 4). A single, very heavy thinning from below (TB1/70) resulted in an increase in spiral grain that lasted for 10 years. Thereafter the grain angle decreased towards the bark. The grain angle in the sample trees in the light-thinned stand (TB6/

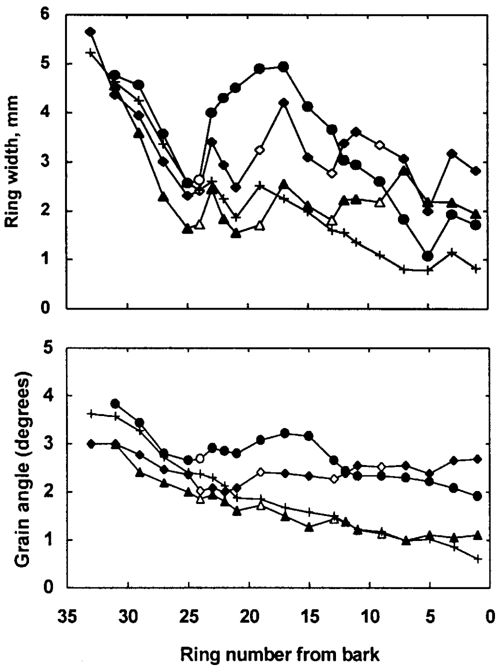

**Fig. 4.** Ring width and spiral grain in trial 949. Thinning regimes: TB6/20 (◆), TB1/70 (●),TA6/20 (▲), T0/0 (+). Unfilled breakpoints represent growth rings formed just prior to thinning.

20) increased slightly towards the bark after a decrease from the pith up until the first thinning. Spiral grain in the sample trees subjected to thinning from above (TA6/20) did not seem to be affected by the thinnings, and the pattern of change towards the bark was similar to that of trees from the naturally thinned stand (T0/0). However, a slight increase in the grain angle of the growth rings closest to the bark was noticeable for TA6/20 compared with T0/0.

# 4 Discussion

## 4.1 Tangential Variation of Spiral Grain within a Growth Ring

The method used in this investigation is based on one mean value from two opposing radii of one annual growth ring (Brazier 1965). This means that if there is a large amount of tangential variation within one annual growth ring, as was found for Douglas-fir (Wobst et al. 1994) and Norway spruce (Bues 1992), this method could not be used to investigate general trends in the formation of spiral grain. However, there was a fair degree of consistency in the radial variation in spiral grain between the two directions measured (Fig. 1, Table 3). The correlation of 0.86 between the two directions was very similar to that reported by Danborg (1994b) for Norway spruce and by Brazier (1965) for larch. Thus, the results of this study can be considered to represent general trends in the formation of spiral grain in the radial direction.

## 4.2 Radial Variation in Spiral Grain within and between Trees

During the last few decades, there has been a trend towards the use of wider initial spacings and fewer, but heavier thinnings in commercial forests in Sweden. In addition, wood grown on former agricultural land, which is generally characterized by high site indexes, has become more common. As a result, tree growth rates have increased (Elfving and Tegnhammar 1996). The positive correlation between grain spirality and diameter growth rate found in several studies (Brazier 1967, Pedini 1990, Becker and Wobst 1993, Danborg 1994b) suggests that an increase in growth rate should contribute to the development of spiral grain. However, in a number of other investigations no such relationship was found (Krempl 1970, Bues 1992, Jensen 1994a).

In the present investigation the effect of ring number was significant in all stands, whereas the effect of ring width on grain angle was only significant in five of the eight stands (Table 4). In accordance with the results of Danborg (1994b), the partial correlation between grain angle and ring width varied between trees (Table 6). The effect of ring number can be considered to reflect the influence of genetic factors. Thus the results of the present investigation also suggest that there is no simple connection between diameter growth rate and spiral grain and emphasize that spiral grain is under considerable genetic control (Harris 1989).

The general grain angle pattern observed in the present study was left-handed spirality in the inner rings that decreased outwards towards the bark (Figs. 2 to 4). In some trees there was a changeover to right-handed spiral grain. However, the between-tree variation in grain angle was high, and patterns differed between trees within each of the stands. Different patterns of spiral grain within a stand, e.g. increasing left-handed spiral grain towards the bark in some trees or no change in spiral grain towards the bark, have also been reported in several other investigations (Hartig 1895, Northcott 1957, Lowery 1966, Bues 1990, Koch and Schlieter 1991, Jensen 1994a).

Although the silvicultural treatment of a stand might not change the pattern of spiral grain, its expression might be affected (Harris 1989). Bergstedt and Jørgensen (1997) reported that heavy thinnings contributed to maintaining a high grain angle or increased it. The present investigation confirmed this. It was found that in some cases a considerable increase in growth rate caused by thinnings was accompanied by an increase in grain angle. In trial 949, after a single heavy thinning that removed 60 % of the basal area of the stand (TB1/70), both ring width and grain angle increased during the seven years immediately following the thinning, whereupon the grain angle decreased again towards the bark (Fig. 4). A similar pattern of development was found in trial 941; i.e. after thinning in the TB3/40 stand the spiral grain stopped decreasing for some years (Fig. 3). In the other two thinning regimes, TB6/20 and TA6/20, in trials 682 and 941, no clear effect of thinning on spiral grain was observed. Since the thinning intensity was lower, the effect on growth rate was less pronounced or absent (Figs. 2, 3).

In the TB6/20 stand in trial 949 grain angle increased towards the bark after the first thinning (Fig. 4). The statistical analysis did not show a significant effect of ring width on spiral grain (Table 4), and none of the nine sample trees showed a high positive correlation between grain angle and ring width (Table 6). Thus, it was not possible to determine whether this was an effect of thinning or whether these trees had a different genetically determined general pattern of spiral grain. Similar patterns were also reported in several other investigations in which silvicultural methods were not considered (Hartig 1895, Northcott 1957, Lowery 1966, Bues 1990, Koch and Schlieter 1991, Jensen 1994a). Becker and Wobst (1993) reported that variation in the grain angle of trees was higher in a thinned stand than in an unthinned one, while the stands were nearly identical in all other respects. Thus, although light thinnings also might affect spiral grain, the effects are not predictable and probably differ from stand to stand since spiral grain formation is controlled genetically to a large extent (Harris 1989).

Most of the studies in which grain angle was found to increase with growth rate relate to results of comparisons between trees within a given stand (Elliott 1958, Pedini 1990, Danborg 1994b). In the present investigation this relation was even found between stands in trial 949, where the naturally thinned stand (T0/0) and the stand thinned from above (TA6/20) were found to have the lowest mean ring width and grain angle, whereas mean values for both variables were highest for the very heavily thinned stand (TB1/70). However, this was not the case in trial 941 where the trees from the stand thinned from above (TA6/20) had the highest mean grain angle, while the stand thinned heavily from below (TB3/40) had the highest mean ring width (Table 2). Since the sample trees in this trial were removed by thinning they represented different dominance classes. Trees removed by thinning from above were all dominant trees, while those removed from the other stands were intermediate or suppressed. The fact that no simple relation exists between diameter growth rate and grain angle suggests that crown size might have some impact on spiral grain. Dominant trees were found to have higher grain angles than intermediate ones (Paul 1956), whereas Elliott (1958) found that the effect of crown class on the development of spiral grain was weak or absent.

Spiral grain has been found to increase tree stability against stem breakage in areas with strong prevailing winds (Thunell 1951, Skatter and Kucera 1997). The findings of this study suggest that wind might contribute to spiral grain. Trees with the highest growth rate usually also are the tallest trees in a stand and are therefore more exposed to wind. In addition, thinning opens up the stand, thereby exposing the residual trees to even more wind. Thus, growth rate and wind affect spiral grain in the same direction.

### 4.3 Practical Implications

There is no doubt about the practical importance of spiral grain for sawn products (Northcott 1965, Danborg 1994a, 1994b, Perstorper et al. 1995, Forsberg 1997). Trees with large grain angles should be avoided for timber production. However, since no simple relation exists between growth rate and grain angle – and thus the environmental effects on grain spirality are not generally predictable (Harris 1989, Jensen 1994b) – it is difficult to recommend any silvicultural treatments with the aim of minimizing spiral grain. Based on the results in this study it is clear that very heavy thinnings should be avoided in stands used primarily for timber production owing to the risk for increased problems with spiral grain. This has also been shown earlier with respect to other wood properties (Pape 1999a, 1999b). It might be possible to maximize growth rate when grain angles are smallest and vice versa. One way to accomplish this might be to decrease initial spacing and use selective thinning. Thinning from above will reduce the juvenile wood content (Pape 1999b). Therefore the mean grain angle will decrease because the maximum grain angle usually occurs within the inner 10–15 growth rings. This would be both an effect of lower growth rate and additionally of a lower content of wood with high grain spirality. Although later thinnings might increase grain angle somewhat, based on the general pattern of spiral grain, it seems most likely that only the decrease in left-handed spiral grain towards right-handed spirality might slow down.

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