International Conference 'Wind Effects on Trees'
September 16-18, 2003, University of Karlsruhe, Germany

THE EFFECT OF GROWTH SPACE CHARACTERISTICS ON THE TREE GROWTH RESPONSE WITH RESPECT TO TREE MECHANICS AND INTERNAL STEM PROPERTIES

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Abstract

This paper presents preliminary investigations on the relation between wind shelter within the stand and tree and stem characteristics. The focus is given to compression wood formation and its distribution within the stem with respect to the growth space characteristics (size, orientation towards main wind direction).

Introduction

The growth space summarises a whole set of key site and stand properties above and below ground such as competition for light, rooting space, availability of water and nutrients, microclimatic modifications and wind shelter. Gardiner et al. (1997) could show how the wind flow mechanisms vary within a stand depending on the distribution pattern of the trees and how wind speed and relative bending moment on the subject tree change with gap size. Thus the available growth space influences fundamentally the individual tree growth response. Silvicultural management aims to use spacing to promote optimal growth conditions in order to maximise volumetric increment and to control wood quality features. Although, to date the mechanical mechanisms controlling tree growth are not fully understood. The wood industry is worried about declining wood quality of softwood grown under larger mechanical constraints due to larger gap size within the stand. Enhanced compression wood formation and increasing number of pitch pockets are identified of being related to those changed growth conditions (Wernsdörfer, 2001). However, no "index" or measure exists which allows to quantify the "shelter" effect of the adjacent or "competing" trees within the stand structure. In a first attempt to describe the shelter effect of competitors, trees grown under different degree of competition for light were investigated in order to test different measures of growth space and competition index measures as predictors for compression wood in spruce.

Material and methods

Six Norway spruce trees (three trees each from two spacing trials) were sampled in order to test different growth space characteristics and competition indices as a measure for a "shelter index" which could be used as a prediction tool for compression wood content and its cross sectional distribution within the stem. Site and tree characteristics are given in Table 1 and 2.

The spacing trial is located in the Forest District Zusmarshausen, Bavaria, Germany.

Location	Zusmarshausen, Scheppacher Forst, Parzelle 603
Species, age	Picea abies, 37 years (2001)
Altitude, exposition, slope	505 m, south, 13-28%
Soil type	Brown earth
Silvicultural management	Line thinning at age 16 to 10000 resp. 2500 trees, crop tree selection at age 21, 26, 32
Spacing trial	Spacing 1 (plot 4): 10000 >> 1900 trees/ha Spacing 2 (plot 6): 2500 >> 600 trees/ha

Tab. 1: Site and stand characteristics

	Spacing 1: 10000 >> 1900			Spacing 2: 2500 >> 600		
	narrow			wide		
Tree ID	247	606	672	73	94	157
Height [m]	21.6	21.4	19.1	22.9	23.2	23.9
Dbh [cm]	24.4	23.0	20.9	28.1	29.1	33.6
h-to-d-ratio [/]	88.5	93.0	91.4	81.5	80.1	71.1
Crown length [m]	10.7	10.8	9.1	13.7	13.2	16.3
Crown width [m]	1.8	1.5	1.6	4.5	5.4	6.0

Tab. 2: Tree characteristics

The standing subject trees and their nearest competitors were precisely described by tree height, dbh, crown length, vertical crown projection area. For the competitors, their exact position in relation to the subject tree was identified by x-, y- and z-co-ordinates.

After felling, 9-10 stem discs were sampled along the stem with variable distance of 2-3m in order to avoid branches in the cross section. The discs were dried, the surface planed and images captured using a scanner to allow image analysis for compression wood identification. Compression wood was identified by optical inspection and colour. Compression wood was colour coded and the images further processed applying a combined image analysis procedure (Wernsdörfer 2001) using Photoshop 6.1 and ScionImage software tools calculating relative compression wood area in the disc surface and its azimuth orientation.

Compression wood orientation and content were correlated to five measures for competition indices which were developed to explain individual tree growth, crown development or population dynamics within stands. The following indices were used:

1. *Directional agglomeration index* (Pukkala 1989, Mäkinen 1997, modified):

$$AI = \left(\left(x_j - \overline{x_j} \right)^2 - \left(y_j - \overline{y_j} \right)^2 \right)^{0.5}$$

with $\overline{x_j} = \sum_{\substack{i=1 \\ i \neq j}}^{n} w_i \cdot \overline{x}_i \Big/ \sum_{\substack{i=1 \\ i \neq j}}^{n} w_i$ and $\overline{y_j} = \sum_{\substack{i=1 \\ i \neq j}}^{n} w_i \cdot \overline{y}_i \Big/ \sum_{\substack{i=1 \\ i \neq j}}^{n} w_i$

$$AI1: w_i = a_i \cdot (h_j / h_i) \qquad AI2: w_i = a_i \cdot (c\_width_j / c\_width_i)$$

with
x_i, y_i = mean x-, y- co-ordinates of the competitors
x_j, y_j = x-, y- co-ordinates of the subject tree
w_i= weighing factor

α= horizontal angle for the co-ordinate point of subject tree to both edges of the crown of tree i, calculated at crown base
h= tree height
c_width= crown width at crown base
n= number of neighbours nearer than selected distance

2. *HEMIS* (Seifert & Pretzsch, in press)

HEMIS is a competition sub-model implemented in the growth simulator SILVA 2.1 (Pretzsch 2001, Pretzsch et al. 2002) and is based on a hemispherical projection method. A fisheye approach is used to calculate the light competition in different compass directions for every chosen point along a stem axis of a tree. The application of the method denotes areas of higher and lower light competition within the surrounding of the subject tree and allows a 360 degrees perspective. For the estimation of shelter effects by competition an aggregation of these values to eight compass directions using averages was carried out. The HEMIS values range from 0 (no competition, minimum shelter) to 1 (maximum competition, maximum shelter).

3. *Competition index after Schütz* (1989)

$$KZ = \sum_{\substack{i=1 \\ i \neq j}}^{n} \left(0.65 \cdot \frac{H_i - H_j}{D_{ij}} + (0.5 - \frac{E_{ij}}{D_{ij}}) \right)$$

with
KZ= competition index
H_i, H_j= height of competitor and subject tree
D_{ij}= distance between subject tree and competitor
E_{ij}= distance between extreme radius of both trees

4. *Competition index after Hegyi* (1974)

$$CI = \sum_{\substack{i=1 \\ i \neq j}}^{n} \left(\frac{c\_width_j}{c\_width_i} \right)^{1.3} \Big/ D_{ij}^{0.4}$$

with
c_width= crown width at crown base
D_{ij}= distance between subject tree and competitor

5. *Gap size*

The gap size was used as a direct measure for the growth space and calculated using the Gauss formula for polygon area.

$$2F = \sum_{i=1}^{n} y_i \cdot (x_{i-1} - x_{i+1})$$

with
x_i, y_i = mean x-, y- co-ordinates of the competitor' stem base
n= number of neighbours nearer than selected distance

Results

The individual trees show a wide range in compression wood proportion and measures of shelter/competition. Table 3 shows the details for compression wood proportion and the competition indices for the individual trees.
Gap size, height-weighted and crown-width weighted aggregation index (AI1, AI2) and CI (Hegyi) differ significantly between the two spacing variations (α=0.05). Mean Hemis index and KZ (Schütz) do not differ between “narrow” and “wide” spacing. Mean compression wood area reflects this and ranges widely between 2.2 % and 8.5 % with no significant difference between the two spacing variations (α=0.05).

	Spacing 1: 10000 >> 1900			Spacing 2: 2500 >> 600		
	“narrow”			“wide”		
Tree ID	247	606	672	73	94	157
Compression wood content [%] (mean ± standard deviation, n)	2.19±2.36 9	5.87±3.93 9	2.35±2.11 8	6.14±4.36 9	4.38±2.99 9	8.50±4.47 10
Compression Wood orientation [°] (mean ± standard deviation, n)	196±99 9	223±83 9	166±76 6	84±110 9	275±100 9	171±133 9
Hemis	0.41	0.36	0.44	0.49	0.41	0.42
AI1	29.68	51.85	56.49	0.59	0.93	6.79
AI2	36.87	83.35	71.06	22.99	9.05	0.17
CI	16.81	13.99	13.81	5.91	4.24	3.23
KZ	-1.3	-49.15	-23.07	-41.97	-38.41	-37.22
Gap size [m²]	32.76	12.9	27.8	62.36	97.43	81.84

Tab. 3: Results on compression wood content and competition indices

Compression wood

The mean percentage of compression wood within a cross section area and its compass orientation varies strongly along the stem height and between the individual trees (Fig. 2 and 3). Overall, compression wood percentage varied between 0 and 17 % on the individual discs. There is no obvious trend in variation along the stem axis and sharp changes in compression wood percentage within short distance along the stem occur. This might be related to varying swaying intensity of single stem parts. The main orientation of the compression wood area also changes during tree growth and in the individual stem heights. It varies for the individual between 0° (N) ...180 (S) ... 360° (N). Though the compass direction of the compression wood within a cross section will be influenced by the main wind direction, the available growth space and its orientation are likely to modify the subsequent orientation of the centre of gravity of the formed compression wood.

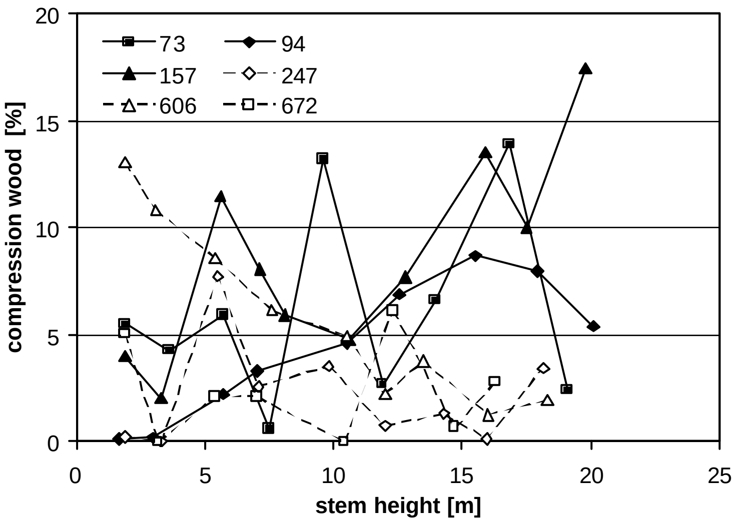

Fig. 2: Variation of compression wood proportion

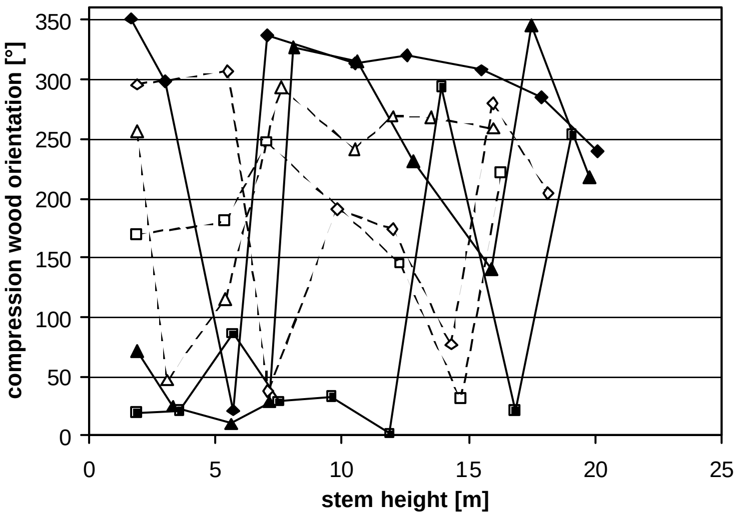

Fig. 3: Variation of mean compass orientation of compression wood with stem height

Competition indices and shelter effects

Figure 4 shows the correlation between amount of compression wood and the competition indices AI1 (weighted by tree height), AI2 (weighted by crown width), CI after HEGYI, KZ after Schütz and gap size. With increasing competition for light and growth space the amount of compression wood generally decreases for all indices and measures. However, due to the small number of trees, R^2 for the different indices and measures ranges from 0.18 to 0.52 with highest R^2 for CI and KZ. Table 4 presents Pearson' s correlation co-efficient for the individually tested correlations for all indices. None of the indices shows a strong linear correlation between compression wood and competition on a statistical significant level (α=0.05).

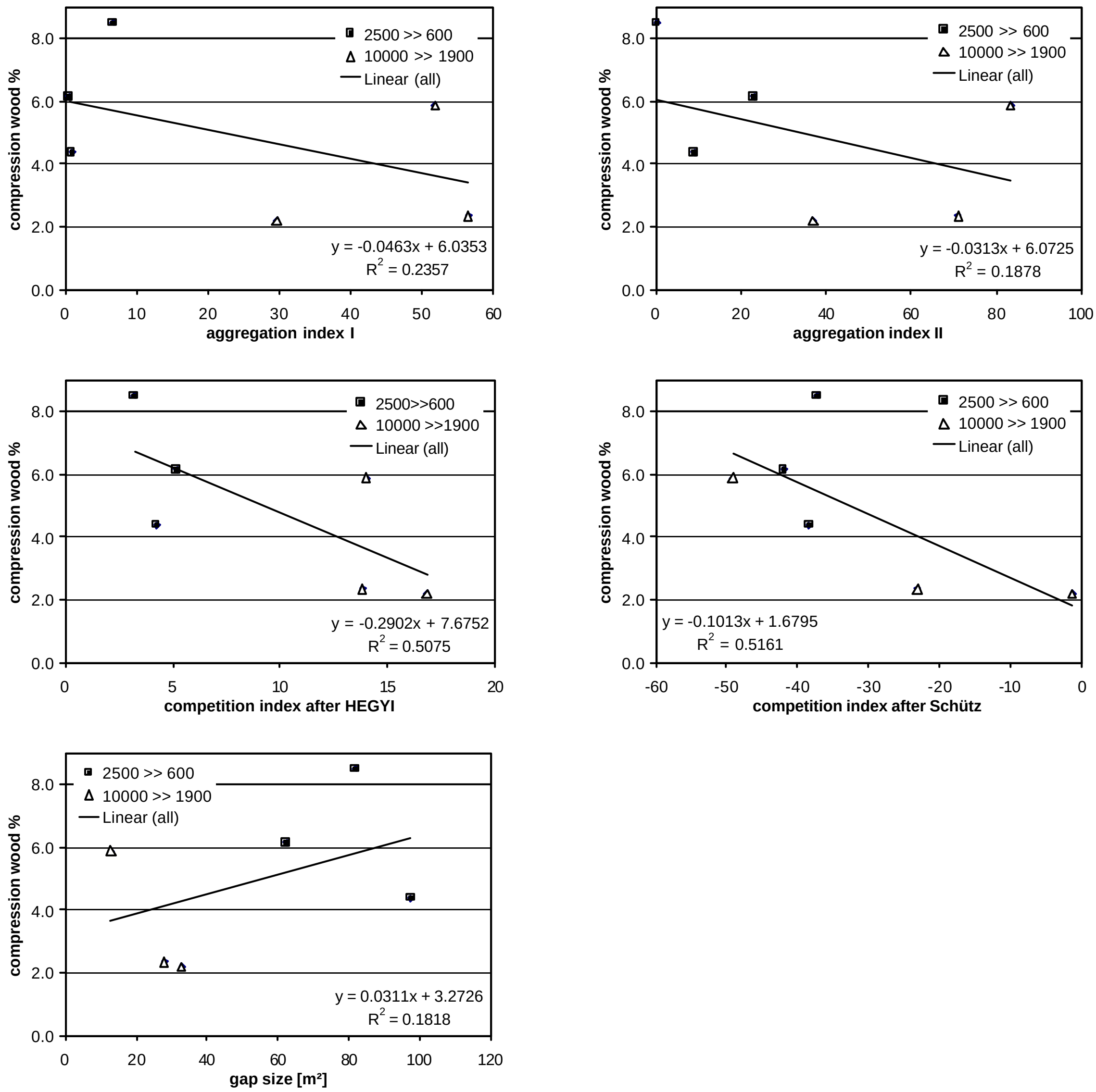

Fig. 4: Proportion of compression wood with variation in competition and shelter

	Pearson coefficient	α
AI1	-0.486	0.329
AI2	-0.433	0.391
HEMIS	-0.052	0.922
HEGYI	-0.712	0.122
SCHÜTZ	-0.718	0.108
GAP SIZE	0.426	0.399

Tab. 4: Pearson coefficients between compression wood % and tested competition indices

Discussion

This paper presents a first approach to derive measures for the wind shelter effect from data characterising spatial competition within a stand and individual tree characteristics. These measures are correlated to the proportion of compression wood in individual trees. The tested distance-dependent indices and measures generally show a shelter effect of increasing spatial competition present as lower compression wood amount. This might be related to less mechanical constraints, less tree swaying and reduced movements, during wood formation under larger spatial competition. However, the presented correlation are weak, due to the small number of trees observed and their large variation in compression wood content. Future work aims to enlarge the data basis and to refine the applied indices to a more precise correlation.

Acknowledgements

The author would like to thank H. Pretzsch and T. Seifert (University of Munich (TU), Germany) for the kind co-operation and providing the opportunity for material and data collection in the spacing trials in Zusmarshausen. T. Seifert also supported this work with data on the tree characteristics and calculated the HEMIS competition values. B. Gardiner, Forestry Commission (UK), and H. Mäkinen (METLA, Finland) helped with fruitful discussion on wind flow on sites and the application of competition indices.

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