Acknowledgements

This study was supported by a grant from the Ministère des Affaires Etrangères, du Commerce Extérieur et de la Coopération Luxembourgeois, Luxembourg. The authors are thankful to Dr. L. Hoffmann for the helpful suggestions.

References

Al-Ahmad, M., Hughes, H. and Safadi, F.: Studies on stomatal function, epicuticular wax and stem-root transition region of polyethylene glycol-treated and non treated *in vitro* grape plantlets. *In vitro* Cell Dev. Biol. **34**: 1–7 (1998). — Blanke, M.M. and Blecher, A.R.: Stomata of apple leaves cultured *in vitro*. Plant Cell Tiss. Org. Cult. **19**: 85–89 (1989). — Brainerd, K.E. and Fuchigami, L.H.: Stomatal functioning of *in vitro* and greenhouse apple leaves in darkness, manitol, ABA and CO_2. J. Exp. Bot. **33**: 388–392 (1982). — Bussotti, F. and Grossoni, P.: European and Mediterranean oaks (*Quercus* L.; Fagaceae): SEM characterization of the micromorphology of the abaxial leaf surface. Bot. J. Linnean Soc. **124**: 183–199 (1997). — Capellades, M., Fontarnau, R., Carulla, C. and Debergh, P.C.: Environment influences anatomy and epidermal cells in tissue cultured *Rosa multiflora*. J. Amer. Soc. Hort. Sci. **115**: 141–145 (1990). — Cassels, A.C. and Walsh, C.: The influence of gas permeability of the culture lid on calcium uptake and stomatal function in *Dianthus* microplants. Plant Cell Tiss. Org. Cult. **37**: 171–178 (1994). — Fila, G., Ghashghaie, J., Hoarau, J. and Cornic, G.: Photosynthesis, leaf conductance and water relations of *in vitro* cultured grapevine root stock in relation to acclimatization. Physiol. Plant. **102**: 411–418 (1998). — Gamborg, O.L., Miller, R.A. and Ojima, K.: Nutrient requirements of suspension cultures of soybean root cells. Exp. Cell Res. **50**: 151–158 (1968). — Greshoff, P.M. and Doy, C.H.: Development and differentiation of haploid *Lycopersicum esculentum* (tomato). Planta. **107**: 161–170 (1972). — Kozai, T., Kubota, C. and Jeong, B.R.: Environmental control for the large-scale production of plants through *in vitro* techniques. Plant Cell Tiss. Org. Cult. **51**: 49–56 (1997). — Lee, N., Wetzstein, H.Y. and Sommer, H.E.: Quantum flux density effects on the anatomy and surface morphology of *in vitro-* and *in vivo*-developed sweetgum leaves. J. Amer. Soc. Hort. Sci. **113**: 167–171 (1988). — Marin, J.A. and Gella, R.: Is desiccation the cause of the poor survival rate in the acclimatization of micropropagated *Prunus cerasifera* L. Ann. Rev. Bot. **62**: 662–670 (1988). — Murashige, T. and Skoog, F.: A revised medium for growth and bioassays with tobacco tissue cultures. Physiol. Plant. **15**: 437–497 (1962). — Pospisilova, J.: Hardening by abscisic acid of tobacco plantlets grown *in vitro*. Biol. Plant. **38**: 605–609 (1996). — Ross-Karstens, G.S., Ebert, G. and Ludders, P.: Influence of *in vitro* growth conditions on stomatal density, index and aperture of grape, coffee and banana plantlets. Plant Tiss. Cult. Biotech. **4**: 21–27 (1998). — Sampson, J.: A method of replacing dry or moist surfaces for examination by light microscopes. Nature **191:** 932 (1961). — Santamaria, J.M., Davies, W.J. and Atkinson, C.J.: Stomata of micropropagated *Delphinium* plants respond to ABA, CO_2, light and water potential, but fail to close fully. J. Exp. Bot. **44**: 99–107 (1993). — Sciutti, R. and Morini, S.: Modified stomatal characteristics in actively proliferating *in vitro* plum cultures at varying levels of relative humidity. Adv. Hort. Sci. **7**: 157–159 (1993). — Shakle, K.A., Novello, V. and Sutter, E.G.: Stomatal function and cuticular conductance in whole tissue-cultured apple shoots. J. Amer. Soc. Hort. Sci. **115**: 466–472 (1990). — Smith, E.F., Gribaudo, I., Roberts, A.V. and Mottely, J.: Paclobutrazol and reduced humidity improve resistance to wilting of micropropagated grapevines. Hort. Sci. **27**: 111–113 (1992). — Zacchani, M., Morini, S. and Vitagliano, C.: Effect of photoperiod on some stomatal characteristics of *in vitro* cultured fruit shoots. Plant Cell Tiss. Org. Cult. **49**: 195–200 (1997). — Zaid, A. and Hughes, H.G.: Water loss and polyethylene glycol-mediated acclimatization of *in vitro*-grown seedlings of five cultivars of date palm (*Phoenix dactylifera* L.) plantlets. Plant Cell Rep. **14**: 385–388 (1995).

Investigations on the Correlation Pattern in Even-aged Stands of Larch

VI. Relationships Between Single Tree Height and Diameter Measurements and Individual Thiessen Polygon Areas

By M. Hühn[1]) and W. Langner[2])

(Received 14th January 1999)

Summary

The objective of this study was to investigate the relationships between single tree measurements for height and diameter and available individual areas per tree (determined by the areas of Thiessen polygons) in even-aged stands of larch. Extensive data sets from a field trial with 27 entries of *Larix europaea, Larix leptolepis* and their hybrids were available. Single tree measurements for height and diameter of this trial have been analyzed for 6 stages of stand development (ages: 11, 13, 19, 50, 53, 56 years). The correlation between height and area was negative and small (–0.17, –0.18, –0.22, –0.20, –0.28, –0.31), while the correlations between diameter and area are separated into two clearly differentiated parts: negative with small numerical values (–0.15, –0.14, –0.17) for the early period of stand development (up to 19 years) and positive with small numerical values (+0.19, +0.22, +0.24) for the late period of stand development (up to 56 years).

In this study, the areas of Thiessen polygons have proven to be poor predictors of tree height and tree diameter. But, they are a reasonable measure of two-dimensional area available to comparable individuals and may provide useful independent variables for prediction approaches in even-aged populations.

Key words: larch, height, diameter, Thiessen polygon tesselation, competition index, trait-area relationships.

Zusammenfassung

Für die Untersuchung der Beziehungen zwischen Einzelbaummessungen für Höhe und Durchmesser und den verfügbaren individuellen Standräumen (hier bestimmt durch die Flächen von Thiessen Polygonen) in gleichaltrigen Lärchenbeständen wurde eine Versuchsfläche mit 27 Sorten von *Larix europaea, Larix leptolepis* und ihren Hybriden ausgewählt, die zu 6 verschiedenen Zeitpunkten der Bestandesentwicklung (Alter: 11, 13, 19, 50, 53, 56 Jahre) einzelbaumweise vermessen wurde. Die Korrelation zwischen Höhe und Standraum ist

---

[1]) Prof. Dr. M. Hühn, Institut für Pflanzenbau und Pflanzenzüchtung der Universität Kiel, Olshausenstrasse 40, D-24118 Kiel, Germany

[2]) Prof. Dr. W. Langner, Dorfstrasse 26, D-23896 Ritzerau, Germany

durchweg negativ und gering (–0,17, –0,18, –0,22, –0,20, – 0,28, –0,31), während die Korrelation zwischen Durchmesser und Standraum in zwei deutlich differenzierte Abschnitte zerfällt: negativ mit niedrigen numerischen Werten (–0,15, –0,14, –0,17) für die „frühe“ Entwicklungsphase (bis zu 19 Jahren) und positiv mit niedrigen numerischen Werten (+0,19, +0,22, + 0,24) für die „späte“ Entwicklungsphase (bis zu 56 Jahren).

Weder für Höhe noch für Durchmesser scheinen daher die Flächen von Thiessen Polygonen geeignete Predictoren zu sein. Nichtsdestotrotz stellen sie jedoch sinnvolle Maßzahlen für den verfügbaren Standraum vergleichbarer Individuen dar und können als nützliche unabhängige Variable bei Leistungsvorhersage-Ansätzen in gleichaltrigen Populationen verwendet werden.

Introduction and Problem

Many studies on tree interference or competition have looked at total population yield and mean yield per individual as a function of density or other independent variables. Mean values, however, obscure tree to tree variation which may be very great. It seems possible to relate some part of the performance of individual trees to the position and nature of their neighbours.

Competition among trees for resources has been studied quantitatively by numerous authors in the fields of silviculture, forest mensuration, forest tree improvement, forest inventory and forest ecology. Many individual-based competition indices were developed to predict the growth of individual trees as a function of interference from a certain subset of other trees in monospecific stands. Each tree competition index characterizes the degree to which the growing space of a tree is shared by other trees. „Most competition indices are considered to be a measure of the degree to which growth resources may be limited by the number, size, and proximity of neighbours. The resources involved and their absolute availability may not be well defined, but may include, at least conceptually, light, water, nutrients, and physical growing space. Other competition measures have been developed that attempt to quantify the relative availability of resources. Point density measures are an attempt to quantify the density affecting a given point (or tree) in a stand. These measures may be thought of as competition indices that express a tree's competitive status in terms usually associated with stand level density measures, such as trees or basal area per hectare.

The biological processes involved in competition among trees are much more complex than can be described by a single mathematical index. However, such indices do provide measures of the outcome of these processes and they have been found useful in predicting tree growth“ (Daniels et al., 1986).

Numerous investigations have been published where a knowledge of tree locations and their sizes had improved the ability to characterize between - tree competition (Opie, 1968; Lin, 1969; Bella, 1971; Moore et al., 1973; Hegyi, 1974; Daniels, 1976; Alemdag, 1978; Pelz, 1978; Noone and Bell, 1980; Doyle, 1983; Tuscan and McKinley, 1984; Daniels et al., 1986; Pukkala and Kolström, 1987; Corona and Ferrara, 1989; Mugasha, 1989; Biging and Dobbertin, 1992 and 1995; Burton, 1993). But, on the other side, there has been also considerable controversy in the literature as to whether tree spatial information improves predictions of individual tree growth. Many experimental data have been published which support the alternative hypothesis that tree spatial information does not add to our ability to characterize between-tree competition: Hatch et al. (1975), Lorimer (1983), Martin and Ek (1984), Daniels et al. (1986), Biging and Dobbertin (1992 and 1995), among others.

In general, the results and comparisons on the different competition indices have been quite variable. The performance of a particular index may vary with species, stage of stand development and cultural practices. No index has been shown to be universally superior.

One way to look at the proximity of a tree to its neighbours is through the use of Thiessen or Voronoi polygons (Thiessen, 1911; Cliff and Ord, 1981; Ripley, 1981): the smallest polygon that can be obtained from a map of tree locations represented by points by erecting perpendicular bisectors to the horizontal lines joining the center of the subject tree to the centers of its neighbours / competitors. The polygon around a tree includes all points in the plane which are closer to that tree than to any other. The polygon also defines the immediate neighbours of an individual. Overall density is the reciprocal of mean polygon area per tree. Polygon area is calculated from the coordinates of the polygon vertices. In this modelling approach, the polygon area is the area potentially available for tree growth. This measure partitions the total stand area and the associated resources into those parts which are potentially available for each individual tree. These polygons are, of course, mutually exclusive and collectively exhaustive of the total area. A diagrammatic representation of this area around a tree and some of its neighbours is given in *figure 1*. For the construction of Thiessen-polygons as well as for the calculation of their areas efficient algorithms and computer programs are available (Guibas et al., 1990; Waupotitsch, 1992).

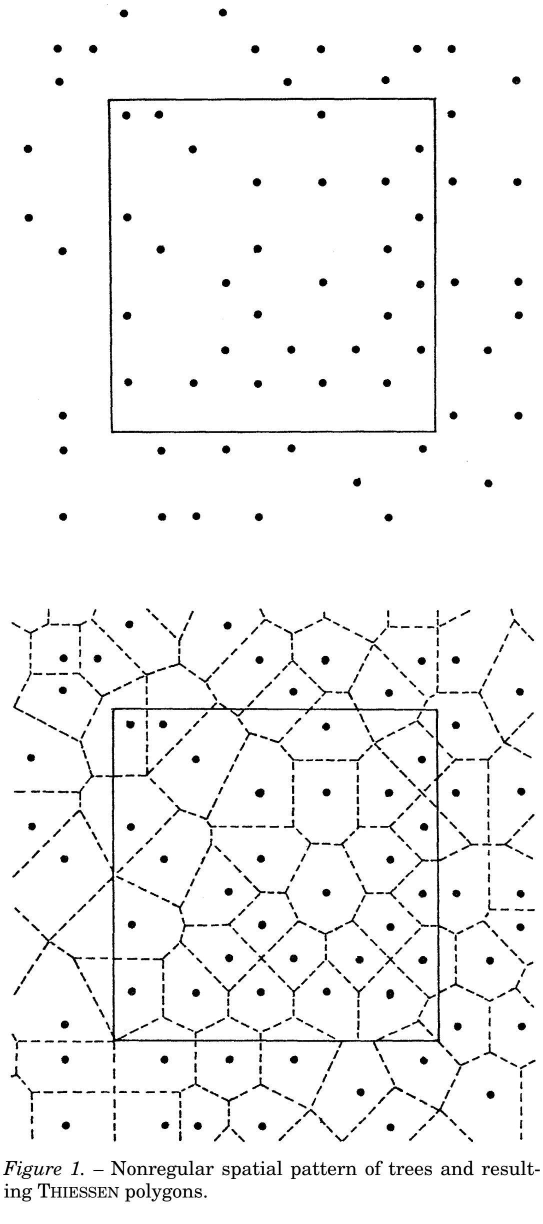

Figure 1. – Nonregular spatial pattern of trees and resulting Thiessen polygons.

By this approach, the area exploited by each tree can be represented by the area of its THIESSEN-polygon and the amount of this area reflects the availability of environmental factors (light, water, nutrients, physical growing space). The basic idea of this modelling approach is the assumption that the trait value of a tree can be considered as a function of available area per tree. In practical forestry, plantations for production purposes are commonly established with regular planting patterns. But, during stand development nonregular patterns necessarily arise by effects of quite different abiotic and biotic factors. Each analysis, therefore, must involve a consideration of temporal changes of the plantation's planting configuration and its spatial neighbourhood pattern. Each realistic description and analysis of tree growth and stand development must incorporate dynamic measures and models of tree interferences and plant community dynamic processes. "Most indices of tree competition are based on various measurements of the abundance, proximity, and stature of neighbouring trees, which are usually measured at only one point in time, i. e. these competition indices are static! They are based on a single set of measurements without any explicit considerations of the many sources of variation within a stand and from year to year". But, "system dynamics cannot be represented by one-time measurements. Perhaps the most important limitation of any competition index is that it is static; it is a representation of the state of a dynamic system at one point in time. Instantaneous assessments cannot unequivocally determine the importance of interference "(BURTON, 1993)" (HÜHN and LANGNER, 1995).

The main objective of this study was to give a non-static description of the relationships between trait measurements for height and diameter at breast height of individual trees and their associated THIESSEN polygon areas for one field trial with larch, i. e. these relationships between trait and area were calculated at different stages of stand development. If such a dynamic analysis detects characteristic temporal patterns or time trends of this relationship dependent on age, this knowledge is of particular importance for many problems in forest tree improvement programs and silvicultural decisions (optimum selection age, characterization of different traits, choice of selection methods, considerations on thinning procedures etc.).

Material and Methods

"This study is based on extensive data sets of single tree measurements for height and diameter at breast height for one even-aged larch population, which had been measured at 7 different stages of stand development (from age 11 up to age 50). The plant material of this field trial consists of 27 entries which belong to 3 groups of different origin *(Larix europaea, Larix leptolepis,* and their hybrids). These 27 entries (5 *Larix europaea,* 15 *Larix leptolepis,* 7 hybrids) have been tested at the site "Gahrenberg" near Göttingen / Germany (degree of longitude 9°36'; degree of latitude 51°28') (area ≅ 6 ha). This Gahrenberg-trial is the oldest experiment in Europe to examine the performance of hybrids relative to their parents (initial crosses in 1936, establishment of the plantation in spring 1939 with 2 years old plants). A detailed description of all interesting aspects (parental material for the crosses, performance of the crosses, nursery practices, characteristics of the site, information on the establishment of the plantation, design, replications, plot size, handling of the measurements etc.) was published by LANGNER (1951, 1952) and we refer to these 2 publications.

This field trial was established as a regular square spacing (5 m x 5 m). These wide plant spacings ensured a delayed beginning of the competitive pressure among neighbouring trees. Competition starts at a stage of stand development when all the competitive interrelationships between crop trees and the noncrop vegetation are eliminated. By this approach a confounding of competitive effects between neighbouring crop trees and competitive effects between crop trees and noncrop vegetation can be avoided "(HÜHN and LANGNER, 1995).

No systematic artificial thinning procedure has been applied. But, nevertheless, a moderate reduction of the number of living trees was observed *(Tables 1* and *2).* These reductions are caused by natural mortality and other unevitable events.

In this study, we are interested in the relationships between single tree trait measurements and individual available area per tree which is quantified by the area of THIESSEN polygons. All individuals with irregular neighbourhood configurations were excluded from the data sets. Thus, only observations with a complete array of neighbours were included in the analyses.

The total area of this Gahrenberg field trial consists of two disconnected separate parts: a very large one (with 29 plots) and a particularly small one (with 4 plots). Both parts are separated by a distance of approximately 27 [m]. To avoid all irregular spatial neighbourhood configurations the analyses of this study were only carried out for the large part (29 plots) of this field trial.

The relationship between single tree measurements and available areas per tree is described by simple product moment or PEARSON correlation coefficients. Tests of significance were carried out by standard procedures from elementary statistics.

Table 1. – Results for single tree measurements, THIESSEN polygon areas, and their correlation coefficients for the trait height at different stages of stand development.

age (in years)	number of trees	single tree measurement		Thiessen polygon area		correlation height-area
		mean	standard deviation	mean	standard deviation	
11	1091	62.47	12.66	4.66	2.90	-0.17
13	1068	73.72	14.12	4.76	2.99	-0.18
19	1020	107.06	18.32	4.98	3.23	-0.22
50	955	244.39	26.87	5.28	3.31	-0.20
53	938	260.09	25.40	5.37	3.44	-0.28
56	920	271.70	28.33	5.46	3.53	-0.31

Table 2. – Results for single tree measurements, THIESSEN polygon areas, and their correlation coefficients for the trait diameter at different stages of stand development.

age (in years)	number of trees	single tree measurement mean	single tree measurement standard deviation	Thiessen polygon area mean	Thiessen polygon area standard deviation	correlation diameter-area
11	1090	98.96	30.31	4.67	2.91	-0.15
13	1067	119.05	33.76	4.77	3.00	-0.14
19	1020	178.76	40.85	4.98	3.23	-0.17
50	950	405.77	63.17	5.27	3.32	+0.19
53	934	418.45	60.27	5.36	3.44	+0.22
56	918	442.15	62.52	5.46	3.53	+0.24

The extensive data sets of single tree measurements of this field trial have been previously used in a series of publications on competitive spatial neighbourhood correlation patterns in even-aged stands of larch (HÜHN and LANGNER, 1992, 1995, 1996a and b). For further details on this field trial (site, plant material, design, plot size, measurements etc.) we refer to these publications.

In addition to the previously handled data sets from HÜHN and LANGNER (1992, 1995, 1996a and b) with measurements from age 11 up to age 50 two additional measurements (ages 53 and 56) were available for this study. The measured traits were height [in dm] and diameter [in mm] at breast height. The coordinates for the map of individual tree locations were measured in an appropriately chosen unit E (1[E] ≅ 3.33[m]) so that polygon areas from *tables 1* and *2* are expressed in the unit 1 [E^2] ≅ 11.09[m^2].

The plant material of this field trial consists of 27 entries which can be divided into 3 groups of entries *(Larix europaea, Larix leptolepis,* and their hybrids). In the investigations of this study, however, no separate analyses of the relationship between single tree measurements and available areas per tree for individual entries or for groups of entries have been carried out. All investigations in this study are based on the collected total plant material.

Results and Discussion

The most interesting results are presented in *tables 1* and *2:* All correlation coefficients between single tree measurements for height and individual areas per tree are negative with small numerical amounts (–0.17, –0.18, –0.22, –0.20, –0.28, –0.31) *(Table 1).* No clear time trend from age 11 up to age 56 can be observed.

The correlation coefficients between single tree measurements for diameter and individual areas per tree, however, can be divided into two clearly separated intervals: early period of stand development (≤ 20 years) with negative correlation coefficients of small numerical amount and late period of stand development (≥ 50 years) with positive correlation coefficients of small numerical amount *(Table 2).* The correlation coefficients within each period are quite similar: –0.15, –0.14 and –0.17 for the early period and + 0.19, + 0.22 and + 0.24 for the late period. The differences between both periods of stand development are clear in sign, but moderate in numerical amount. So, we can conclude that a slightly pronounced time trend from moderate negative correlations (early period) to moderate positive correlations (late period) can be observed.

All correlation coefficients from *tables 1* and *2* are based on very large numbers of observations (918 to 1091). They are, therefore, all significantly different from zero (even for an error probability of 0.01%).

The small numerical amount of the correlation coefficients from *tables 1* and *2* indicate that THIESSEN polygons are poor predictors of tree height and tree diameter – in part because neighbour proximity and number may be less important than differences in other factors (spatial heterogeneity, genetic variation etc.). But, the small correlation coefficients between single tree trait values and individual areas can be also explained by the following considerations: There is strong empirical evidence supported by many experimental studies that the graphs of height growth dependent on space per tree are clear optimum curves, where the maxima (= optima) are obtained for much closer spacings, i. e. a certain competitive pressure of neighbouring trees is necessary for an optimum tree growth [see, for example, DIPPEL (1982)]. In this situation, smaller individual areas are connected with larger individual tree heights, i. e. a negative correlation between trait value and area may be expected. This conclusion / expectation is clearly confirmed by the results from *table 1.* The graphs of diameter growth dependent on space per tree, however, are clear saturation curves where the final asymptotic numerical niveau is obtained for relatively close spacings [see, for example, DIPPEL (1982)]. It is a well-known fact from forestry research that diameter reacts much more sensitive to competitive pressure than height. With increasing age of this wide-spacing trial the number of living trees decreases moderately which leads to larger individual areas per tree, i. e. the competitive pressure is reduced and the subject tree responds with larger values for the trait diameter. In this situation, larger individual areas are connected with larger individual tree diameter, i. e. a positive correlation between trait value and area may be expected for the advanced stages of stand development. This conclusion / expectation is clearly confirmed by the results from *table 2.* For both types of functional relationships between trait and area (optimum curve for height, saturation curve for diameter) increasing individual areas are not necessarily connected with increasing trait values. The correlation coefficients between trait and area, therefore, cannot be large.

The experimental data of this study apparently support the hypothesis that tree spatial information (calculation of distance-dependent competition indices utilizing individual tree location, neighbour proximity and number) does not add to our ability to characterize between tree competition and to improve prediction of individual and populational tree growth. THIESSEN polygon areas seem to be poor predictors of individual tree growth. This situation, however, may be drastically changed in natural stands. In silviculturally established plantations the spacing is relatively controlled and hence knowledge of location is of lesser value. In any case, THIESSEN polygons are a reasonable measure of two-dimensional area available to comparable individuals and may provide useful independent variables (amongst others) for predicting tree growth in even-aged populations – even if this growth can be only partly explained by such purely spatial considerations.

Acknowledgements

The authors gratefully acknowledge the cooperation and help provided by Dr. M. AMESKAMP, Institute of Computer Science and Applied Mathematics, University Kiel (construction and calculation of the THIESSEN polygons), Dr. G. RAVE (statistical analysis), and the technical assistance by Mrs. H. JENSEN and Mrs. B. PALLASCH.

Literature

ALEMDAG, I. S.: Evaluation of some competition indexes for the prediction of diameter increment in planted white spruce. For. Manage. Inst. Inf. Rep. FMR-X-108. 39 p. (1978). — BELLA, I. E.: A new competition model for individual trees. For. Sci. **17**, 364–372 (1971). — BIGING, G. S. and DOBBERTIN, M.: A comparison of distance-dependent competition measures for height and basal area growth of individual conifer trees. For. Sci. **38**(3), 695–720 (1992). — BIGING, G. S. and DOBBERTIN, M.: Evaluation of competition indices in individual tree growth models. For. Sci. **41**(2), 360–377 (1995). — BURTON, P. J.: Some limitations inherent to static indices of plant competition. Can. J. For. Res. **23**, 2141–2152 (1993). — CLIFF, A. D. and ORD, J. K.: Spatial Processes. Models and Applications, Pion Lim., London (1981). — CORONA, P. and FERRARA, A.: Individual competition indices for conifer plantations. Agric. Ecosyst. Environ. **27**, 429–437 (1989). — DANIELS, R. F.: Simple competition indices and their correlation with annual loblolly pine tree growth. For. Sci. **22**, 454–456 (1976). — DANIELS, R. F., BURKHART, H. E. and CLASON, T. R.: A comparison of competition measures for predicting growth of loblolly pine trees. Can. J. For. Res. **16**, 1230–1237 (1986). — DIPPEL, M.: Auswertung eines NELDER-Pflanzverbandsversuchs mit Kiefer im Forstamt Walsrode. Allg. Forst- u. J.-Ztg. **153**(8), 137–154 (1982). — DOYLE, T. W.: Competition and growth relationships in a mixed-aged, mixed-species forest community. Ph. D. diss., Univ. of Tenn. 86 p. (1983). — GUIBAS, L. J., KNUTH, D. E. and SHARIR, M.: Randomized incremental construction of Delaunay and Voronoi diagrams. In: Proceedings of Automata, Languages and Programming. pp. 414-431. 17th Int. Colloq. Warwick Univ., England, July 1990 (1990). — HATCH, C. R., GERRARD, D. J. and TAPPEINER II, J. C.: Exposed crown surface area: A mathematical index of individual tree growth potential. Can. J. For. Res. **5**, 224–228 (1975). — HEGYI, F.: A simulation model for managing jack pine stands. P. 74–90. In: 'Growth models for tree and stand simulation'. FRIES, J. (ed.). Royal Coll. For., Res. Note 30. 379 p. (1974). — HÜHN, M. and LANGNER, W.: Untersuchungen zum Korrelationsmuster von Lärchenbeständen. 1. Mitteilung: Problemstellung, Versuchsmaterial, Auswertungsmethodik sowie theoretische Nachbarschaftskorrelationen. Silvae Genetica **41**, 216–228 (1992). — HÜHN, M. and LANGNER, W.: Investigations on the correlation pattern in even-aged stands of larch. II. Dynamic description of phenotypic correlations between neighbouring observations. Silvae Genetica **44**, 325–334 (1995). — HÜHN, M. and LANGNER, W.: Investigations on the correlation pattern in even-aged stands of larch. IV. Relationships between neighbourhood correlations and means of different entries. Silvae Genetica **45**, 329–336 (1996a). — HÜHN, M. and LANGNER, W.: Investigations on the correlation pattern in even-aged stands of larch. V. Phenotypic correlations between neighbouring observations for *Larix decidua* MILL. (*Larix europaea* DC.) *Larix kaempferi* (LAMB.) CARR. (*Larix leptolepis* (SIEB. et ZUCC.) SIEB. ex GORD.), and *Larix* x *eurolepis* HENRY). Silvae Genetica **45**, 337–342 (1996b). — LANGNER, W.: Kreuzungsversuche mit *Larix europaea* D.C. und *Larix leptolepis* GORD. Teil 1. Zeitschrift für Forstgenetik und Forstpflanzenzüchtung **1**(1), 2–18 (1951). — LANGNER, W.: Kreuzungsversuche mit *Larix europaea* D.C. und *Larix leptolepis* GORD. Teil 2. Zeitschrift für Forstgenetik und Forstpflanzenzüchtung **1**(2), 40–56 (1952). — LIN, J. Y.: Growing space index and stand simulation of young western hemlock in Oregon. Ph.D. thesis, Duke University, Durham, N.C. 182 p. (1969). — LORIMER, C. G.: Tests of age-independent competition indices for individual trees and natural hardwood stands. For. Ecol. Manage. **6**, 343–360 (1983). — MARTIN, G. L. and EK, A. R.: A comparison of competition measures and growth models for predicting plantation red pine diameter and height growth. For. Sci. **30**(3), 731–743 (1984). — MOORE, J. A., BUDELSKY, C. A. and SCHLESINGER, R. C.: A new index representing individual tree competitive status. Can. J. For. Res. **7**, 495–500 (1973). — MUGASHA, A. G.: Evaluation of simple competition indices for the prediction of volume increment of young jack pine and trembling aspen trees. For. Ecol. Manage. **26**, 227–235 (1989). — NOONE, C. S. and BELL, J. F.: An evaluation of eight intertree competition indices. For. Res. Lab. School of For. Oregon State Univ. Corvallis. Res. Note 66. 6 p. (1980). — OPIE, J. E.: Predictability of individual tree growth using various definitions of competing basal area. For. Sci. **14**, 314–323 (1968). — PELZ, D. R.: Estimating individual tree growth with tree polygons. P. 172–178. In.: 'Growth models for long term forecasting of timber yields'. FRIES, J., H. E. BURKHART and T. A. MAX, (eds.). Va. Polytech. Inst. State Univ., Sch. For. Wildl. Resour., FWS-1–78 (1978). — PUKKALA, T. and KOLSTRÖM, T.: Competition indices and the prediction of radial growth in Scots pine. Silva Fennica **21**(1), 55–67 (1987). — RIPLEY, B. D.: Spatial Statistics. John Wiley and Sons, New York (1981). — THIESSEN, A. H.: Precipitation averages for large areas. Monthly Weather Reviews **39**, 1082–1084 (1911). — TUSKAN, G. A. and MCKINLEY, C. R.: The use of competition indices in advanced-generation selection. Silvae Genetica **33**(6), 209–215 (1984). — WAUPOTITSCH, R.: NCSA MinMaxer. National Centre for Supercomputing Applications, Champaign, Illinois, USA (1992).