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

IV. Relationships between Neighbourhood Correlations and Means of Different Entries[1])

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Summary

For a dynamic description of spatial neighbourhood correlation patterns of stands of larch and an analysis of temporal changes and time trends of such patterns during stand development extensive data sets from a field trial (trial no. 1) with 27 entries of *Larix decidua* Mill. (*Larix europaea* DC.), *Larix kaempferi* (Lamb.) Carr. (*Larix leptolepis* (Sieb. et Zucc.) Sieb. ex Gord.), and *Larix* x *eurolepis* Henry have been used. Single tree measurements of this trial were available for 7 stages of stand development (ages: 11, 13, 18, 19, 42, 49 and 50 years).

Additionally, for a static description of spatial neighbourhood correlation patterns of stands of larch extensive data sets from 9 field trials (trials nos. 2 to 10) with a varying number (8 to 23) of entries have been used which provide an analysis of the correlations between neighbours at only one point in time. These trials are slightly different in their ages (7 to 11 years).

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[1]) Dedicated to Prof. Dr. W. Langner on his 90th birthday.

Note: This paper is dedicated to Prof. Dr. W. Langner although he himself serves as a co-author. This publication is a result of common research between the senior author and Prof. Dr. W. Langner who prepared the extensive data sets from some of his trials with larch as an empirical basis for these correlation studies.

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Single tree measurements for all 10 trials were available for the traits height and diameter at breast height (for the 2 ages 42 and 49 of trial no. 1 only diameter measurements were available). Additionally, the diameter values are transformed and analysed as individual basal areas.

The correlative structure for measurements of neighbouring individuals for these trials with regular square spacings (5 m x 5 m for trial no. 1 and 1.5 m x 1.5 m for trials nos. 2 to 10) has been described by 12 different correlation coefficients. These coefficients are defined by considering quite different spatial configurations of competitive neighbourhoods. In these procedures and analyses the diagonally located neighbours of a subject tree and its missing neighbours too are explicitly considered.

The question of this paper is: Are there any relationships between means and spatial neighbourhood correlations for the different entries?

Relationships valid for all traits, for all trials and for all ages = stages of stand development have not been observed for this plant material.

Some interesting special results were obtained - for example:

1. For the dynamic description during stand development of trial no. 1, relationships among the yields of competing neighbours are independent on the yield level. With regard to the amount of the rank correlations (positive or negative) between means and spatial neighbourhood correlations for most cases one obtains: {height} ≥ {diameter} ≅ {individual basal area}.

2. For the static description of the trials nos. 2 to 10 (each with only 1 measurement) the results strongly depend on the individual trial.

Key words: correlation pattern, neighbourhood correlation, height, diameter, individual basal area, larch.

FDC: 165.41; 165.72; 165.51; 232.13; 174.7 *Larix decidua;* 174.7 *Larix leptolepis.*

Zusammenfassung

Für die dynamische Betrachtung des räumlichen Korrelationsmusters von Lärchenbeständen, d. h. für die Analyse der Nachbarschaftskorrelationen eines Bestandes zu unterschiedlichen Zeitpunkten seiner Entwicklung, wurde eine Versuchsfläche (Versuch Nr. 1) mit 27 Sorten von *Larix decidua* MILL. (*Larix europaea* DC.), *Larix kaempferi* (LAMB.) CARR. (*Larix leptolepis* (SIEB. et ZUCC.) SIEB. ex GORD.) und *Larix* x *eurolepis* HENRY ausgewählt, die zu 7 verschiedenen Zeitpunkten der Bestandesentwicklung (Alter: 11, 13, 18, 19, 42, 49 und 50) einzelbaumweise vermessen wurde. Zusätzlich wurden für eine statische Betrachtung des räumlichen Korrelationsmusters von Lärchenbeständen, d. h. für die einmalige Analyse der Nachbarschaftskorrelationen eines Bestandes zu einem bestimmten Zeitpunkt seiner Entwicklung, 9 weitere Versuchsflächen (Versuche Nr. 2 bis 10) mit einer unterschiedlichen Anzahl (8 bis 23) an Sorten herangezogen, die zu etwas verschiedenen Altersstufen (7 bis 11 Jahre) einzelbaumweise aufgenommen wurden. Die erhobenen Merkmale sind Höhe und Durchmesser (beim Versuch Nr. 1 stehen für die beiden Alter 42 und 49 nur Durchmessermessungen zur Verfügung). Zusätzlich wurden die Durchmesserwerte transformiert und als individuelle Grundflächen ausgewertet.

Die Nachbarschaftskorrelationsstruktur der im quadratischen Verband angelegten Lärchenbestände (5 m x 5 m für Versuch Nr. 1 und 1,5 m x 1,5 m für Versuche Nr. 2 bis 10) wird durch 12 verschiedene Korrelationskoeffizienten beschrieben, die durch die Heranziehung von unterschiedlichen räumlichen Nachbarschaftskonfigurationen definiert werden. Dabei werden auch diagonal entfernt stehende Nachbarn sowie auch fehlende Nachbarn explizit in die Ansätze und Auswertungen mit einbezogen.

In der vorliegenden Arbeit wird die Frage untersucht: Gibt es irgendwelche Beziehungen zwischen den für die einzelnen Sorten berechneten Nachbarschaftskorrelationen und den Sortenmittelwerten?

Gesetzmäßigkeiten, die für alle Merkmale, für alle Versuche und für alle Altersstufen gültig sind, weist das hier untersuchte Material nicht auf. Man findet jedoch interessante Einzelresultate, wie z. B.:

1. Bei der dynamischen Betrachtung des Versuchs Nr. 1 sind die Beziehungen zwischen den Merkmalswerten benachbarter Individuen vom Leistungsniveau unabhängig.

Für die Straffheit der Rangkorrelationskoeffizienten (positiv oder negativ) zwischen Nachbarschaftskorrelationen und Sortenmittelwerten erhält man in den meisten Fällen: {Höhe} ≥ {Durchmesser} ≅ {individuelle Grundfläche}.

2. Bei der statischen Betrachtung der nur einmalig vermessenen Versuche Nr. 2 bis 10 hängen die Korrelationsresultate sehr stark von dem betreffenden Versuch ab.

Introduction and Problem

Phenotypic correlations between measurements for neighbouring individuals have been widely used for many applications in forest genetics, forest tree improvement, and silvicultural practices. Such studies on spatial neighbourhood correlation patterns are, of course, closely related to the analysis of competition indices and measures of stand density. A frequently used attempt to assess the amount of spatial correlations is the calculation of correlation coefficients for first-, second-, and third-order neighbours. The order of the relationship refers to the spatial closeness of the observations. First-order neighbours share common borders, second-order neighbours have common first-order neighbours etc. For a literature review and a comprehensive discussion of these relationships see HÜHN and LANGNER (1992, 1995).

Static as well as dynamic descriptions (both theoretical and applied) of spatial neighbourhood correlation patterns of even-aged stands of larch have been published in some recent papers (HÜHN and LANGNER, 1992 and 1995; LANGNER and HÜHN, 1995). These studies were based on extensive data sets from 10 field trials with a varying number of entries which belong to 3 groups of different origin: *Larix decidua* MILL. (*Larix europaea* DC.), *Larix kaempferi* (LAMB.) CARR. (*Larix leptolepis* (SIEB. et ZUCC.) SIEB. ex GORD.), and *Larix* x *eurolepis* HENRY.

The correlative structures of these trials for measurements of neighbouring individuals have been described by 12 different correlation coefficients. These coefficients are defined by considering quite different spatial configurations of competitive neighbourhoods. In these procedures and analyses the diagonally located neighbours of a subject tree and its missing neighbours too were explicitly considered.

Single tree measurements were analysed for the traits height, diameter at breast height, and individual basal area.

Results for dynamic descriptions of the spatial neighbourhood correlation pattern (= analysis of temporal changes and time trends of the correlations between neighbours during stand development) have been published in HÜHN and LANGNER (1995) while results for static descriptions (= analysis of the correlations between neighbours at only one point in time) are given in LANGNER and HÜHN (1995). System dynamics, however, cannot be represented by one-time measurements. One of the most important limitation of many of the commonly applied competition indices is their static approach. Instantaneous assessments, however, can only give a representation of the state of a dynamic system at one point in time. Static descriptions of spatial neighbourhood correlation patterns must be, therefore, of an only limited explanatory power.

The field trials used in HÜHN and LANGNER (1992 and 1995) and LANGNER and HÜHN (1995) as well as most plantations for production purposes in practical forestry are commonly established with regular planting patterns, for example regular square spacing. The really existing spatial configurations at the time of measurement, however, are, of course, nonregular due to effects of natural mortality, thinning treatments etc. The effects of missing trees on the resulting spatial correlation patterns are of particular relevance for many applications in forest tree improvement and silviculture.

Actual developments in silvicultural yield and growth research proceed from the traditional volume growth-oriented yield science (= static approaches based on the sums or means of the stands) to a system-oriented science of forest growth (= dynamic approaches based on single stems, i. e. decomposition of the stand into a mosaic of individual trees and modelling of stand development as a dynamic space-time system). An analysis of the development of single stems of a stand dependent on locational conditions and spatial growth constellations requires the construction and handling of competition indices which appropriately reflect the actual growing conditions for individual stems in stands with nonregular spatial patterns (PRETZSCH, 1995). Correlation analysis of spatial patterns of observed measurements for neighbouring trees may provide an useful approach towards an explanation of these quite complex relationships.

In this paper, only one specific topic is considered: Are there any relationships between means and spatial neighbourhood correlations for the different entries?

Material and Methods

The investigations of this study are based on data sets of single tree measurements for height and diameter at breast height for 10 even-aged larch populations. Based on the measurements of diameter, the values for individual basal area have been calculated.

The plant material of the 10 field trials consists of 3 groups of different origin: *Larix decidua* MILL., *Larix kaempferi* (LAMB.) CARR., and *Larix* x *eurolepis* HENRY.

In some recent publications (HÜHN and LANGNER, 1992 and 1995; LANGNER and HÜHN, 1995) a general introduction into problems and concepts of spatial correlation pattern analysis has been given. Furthermore, these papers contain detailed descriptions of the 10 field trials (sites, entries, dates of establishment of the plantations, replications, plot sizes, plant distances, measurements, population sizes). Only some of the most important characteristics of the 10 trials are compiled in *table 1.* For all further information on the plant material, characteristics of the sites, design and analysis of the field experiments etc. we refer to the cited recent papers.

Table 1. – Some characteristics of the 10 field trials used in this study.

field trial no.	location	no. of entries	measurement at age (in years)		population size		overall mean	
			height	diameter	height	diameter	height [dm]	diameter [mm]
1	Gahrenberg	27	11	11	1342	1342	63.17	100.89
			13	13	1323	1323	74.36	121.07
			18	18	1292	1292	100.56	170.28
			19	19	1249	1249	108.27	182.81
			-	42	-	1208	-	372.04
			-	49	-	1198	-	402.70
			50	50	1197	1197	244.57	406.38
2	Oberraden	8	11	11	308	607	36.96	86.35
3	Wissen	15	9	9	264	260	59.17	62.00
4	Lohne	16	11	11	262	262	66.49	70.02
5	Berlin	18	7	7	199	579	15.42	50.06
6	Fürstenau	21	8	9	716	714	41.68	47.08
7	Hesepe	16	8	9	567	564	46.77	53.57
8	Kleinheubach	23	10	10	953	935	55.43	53.31
9	Gammelsbach	18	9	9	685	674	57.43	57.86
10	Segendorf	18	9	9	592	592	65.25	62.82

The 10 field trials have been established as regular square spacings with quite different distances (1.5 m x 1.5 m for trials nos. 2 to 10 and 5 m x 5 m for trial no. 1). Reliable comparisons of the neighbourhood correlation pattern results between the static descriptions of trials nos. 2 to 10 and the dynamic descriptions of trial no. 1 are, therefore, nearly impossible.

Only observations with a complete array of neighbours (still living or already missing at the time of measurement) were included in the analyses, i. e. all border trees were dropped from the analyses.

Based on single tree measurements, simple product moment or PEARSON correlation coefficients were calculated between each single tree measurement and several measures which are based on individual tree measurements of the competing neighbours of the subject tree. These different measures are defined by the consideration of quite different spatial configurations of neighbours which are assumed to be effectively competing neighbours of the subject tree.

The spatial correlation patterns are described by the following correlation coefficients (*Figure 1*):

r_1, r_2, and r_3 =	correlation between subject tree X and sum of its direct, diagonal, and total neighbours.
r_4, r_5, and r_6 =	sum in the previous definition is replaced by mean.
r_7, r_8, and r_9 =	correlation between subject tree X and one of the direct, diagonal, or total neighbours.
r_{10}, r_{11}, and r_{12} =	correlation between subject tree X and number of missing values among the direct, diagonal, or total neighbours.

In this terminology, the neighbours D, B, E, and G of the subject tree X in *figure 1* are direct neighbours, while the neighbours A, C, H, and F are diagonal neighbours (*Fig. 1*).

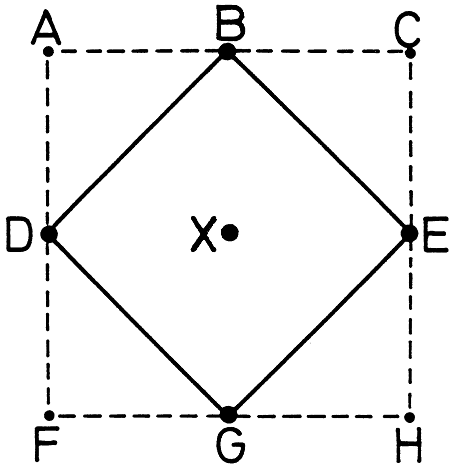

Figure 1. – Competing neighbours (direct and diagonal) for the subject tree X.

The correlation coefficients r_1, r_2, …, r_{12} were calculated as simple phenotypic correlations based on the individual phenotypic measurements.

The plant material of each of these 10 field trials consists of a varying number of different entries (*Table 1*) originating from 3 groups: *Larix decidua* MILL., *Larix kaempferi* (LAMB.) CARR., and *Larix* x *eurolepis* HENRY.

In this paper, the correlation coefficients r_1, r_2, …, r_{12} were separately calculated for each individual entry and correlated with the entry means. In this point of view, the individual entries are considered as replications.

If a spatial neighbourhood correlation coefficient of an individual entry is based on a very small number n of observations, this entry was dropped from the analyses. We decided to include all those entries where a correlation coefficient of 0.50 is significantly different from zero. This condition, of course, is a quite arbitrary one. For this study, however, this approach seems to be reasonable. For an error probability (type I error) of $\alpha = 0.10$ this approach leads to the condition: $n \geq 12$, i. e. all entries with $n < 12$ were dropped from the analyses.

To describe the strength of the relationship between neighbourhood correlations and means, SPEARMAN's rank correlation coefficients have been calculated. The neighbourhood correlation coefficients of the different entries may be positive or negative and, therefore, we used two computational procedures for ranking:

1. Ranking of the correlation coefficients with consideration of the signs of these correlation coefficients, i. e. the strongest negative correlation coefficient obtains the lowest rank number.

2. Ranking of the correlation coefficients without consideration of the signs of these correlation coefficients, i. e. ranking of the absolute values of these correlation coefficients (smallest absolute value = lowest rank number). This procedure is equivalent with a ranking of the coefficients of determination.

But, just this point of view is a quite interesting one: An analysis of the coefficient of determination instead of the spatial neighbourhood correlation itself provides some information to what extent the measurement of a subject tree can be considered to be determined by the measurements of its competing neighbours. With this approach, the relationships among the measurements of a certain neighbourhood configuration (= subject tree and competing neighbours) are described by regression techniques: dependent variable = measurement of subject tree and independent variable = measurements of the competing neighbours of this subject tree.

The relationships between neighbourhood correlations/coefficients of determination and means of the entries are quantitatively described by SPEARMAN rank correlation coefficients which are calculated and tested by elementary statistical standard procedures.

Results and Discussion

The SPEARMAN rank correlation coefficients between spatial neighbourhood correlations/coefficients of determination and

Table 2. – SPEARMAN rank correlation coefficients between means and spatial neighbourhood correlations / coefficients of determination of the different entries for diameter.

		For spatial neighbourhood correlations											
field trial no.	age (in years)	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}
	11	- 0.18	- 0.01	- 0.15	- 0.21	- 0.08	- 0.10	- 0.27	- 0.06	- 0.15	0.01	0.13	0.09
	13	- 0.27	- 0.08	- 0.19	- 0.21	- 0.01	- 0.06	- 0.31	0.04	- 0.17	0.18	0.14	0.12
	18	- 0.34	- 0.06	- 0.30	- 0.27	0.05	- 0.19	- 0.32	0.02	- 0.17	0.28	0.21	0.25
1	19	- 0.32	0.02	- 0.25	- 0.15	- 0.01	- 0.13	- 0.21	- 0.04	- 0.12	0.26	0.09	0.19
	42	- 0.16	0.10	- 0.03	0.17	- 0.20	0.01	0.11	- 0.02	0.00	0.17	- 0.06	- 0.01
	49	- 0.12	0.22	- 0.02	0.11	- 0.13	0.02	0.03	0.07	0.01	0.06	- 0.13	0.01
	50	- 0.17	0.09	- 0.12	0.20	- 0.10	0.07	0.07	0.09	0.09	0.18	- 0.04	0.14
2	11	0.12	0.12	0.14	0.33	0.31	- 0.21	0.19	0.24	- 0.10	0.10	0.05	0.43
3	9	- 0.41	- 0.29	- 0.40	- 0.10	- 0.22	- 0.26	0.13	- 0.43	- 0.59**	0.47	0.42	0.71***
4	11	- 0.10	0.16	0.10	0.14	0.28	0.17	0.23	0.30	0.15	- 0.05	- 0.01	0.11
5	7	- 0.13	- 0.43*	- 0.46*	- 0.21	- 0.17	- 0.23	- 0.23	- 0.12	- 0.21	0.01	0.17	0.12
6	9	- 0.36	- 0.30	- 0.35	- 0.35	- 0.36	- 0.38*	- 0.39*	- 0.35	- 0.38*	0.15	0.18	0.09
7	9	0.21	0.28	0.23	0.21	0.19	0.17	0.21	0.13	0.16	- 0.16	- 0.19	- 0.12
8	10	- 0.11	- 0.16	- 0.11	- 0.21	- 0.23	- 0.17	- 0.28	- 0.11	- 0.16	- 0.08	0.04	- 0.02
9	9	0.03	- 0.09	- 0.01	- 0.07	- 0.28	- 0.24	0.12	- 0.38	- 0.12	0.00	- 0.27	- 0.24
10	9	- 0.17	- 0.17	- 0.23	- 0.31	0.04	- 0.12	- 0.31	0.09	- 0.16	- 0.14	0.16	0.18

		For coefficients of determination of spatial neighbourhood correlations											
field trial no.	age (in years)	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}
	11	- 0.14	- 0.07	- 0.14	- 0.25	0.19	0.10	- 0.19	0.12	0.05	- 0.07	- 0.17	- 0.16
	13	- 0.25	- 0.24	- 0.22	- 0.28	0.24	0.10	- 0.39*	0.25	- 0.06	- 0.17	- 0.12	- 0.10
	18	- 0.41**	- 0.19	- 0.36*	- 0.30	- 0.13	- 0.08	- 0.21	- 0.10	- 0.22	- 0.38*	- 0.58***	- 0.53***
1	19	- 0.08	- 0.06	- 0.22	- 0.14	0.00	- 0.01	- 0.14	0.01	- 0.18	- 0.28	- 0.40*	- 0.47**
	42	0.17	0.01	0.01	- 0.23	0.15	- 0.09	- 0.27	- 0.03	0.15	0.17	0.18	0.02
	49	0.12	- 0.24	0.02	0.10	0.26	0.11	- 0.18	0.05	0.14	0.06	0.07	0.01
	50	0.18	- 0.06	0.12	0.02	0.16	0.13	-0.16	- 0.03	0.06	0.18	0.16	0.14
2	11	- 0.12	- 0.12	- 0.14	- 0.33	-0.14	0.21	- 0.19	0.14	0.10	0.10	0.05	0.43
3	9	0.37	- 0.20	0.09	0.12	- 0.62**	- 0.28	- 0.27	- 0.65**	- 0.51*	0.00	- 0.21	0.39
4	11	0.01	- 0.33	- 0.23	0.10	- 0.08	- 0.04	0.13	- 0.01	0.13	-0.24	- 0.04	0.05
5	7	- 0.12	- 0.43*	- 0.46*	- 0.13	- 0.17	- 0.21	- 0.18	- 0.03	- 0.15	- 0.33	0.00	0.04
6	9	- 0.45**	- 0.30	- 0.42*	- 0.35	- 0.38*	- 0.41*	- 0.32	- 0.29	- 0.39*	0.12	- 0.30	- 0.22
7	9	0.41	0.29	0.39	0.52**	0.22	0.36	0.52**	0.16	0.31	- 0.04	- 0.11	- 0.07
8	10	- 0.43**	- 0.39*	- 0.52**	- 0.22	- 0.47**	- 0.29	- 0.36*	- 0.34	- 0.20	- 0.31	- 0.10	- 0.27
9	9	- 0.08	- 0.20	0.09	- 0.20	- 0.11	0.18	- 0.33	- 0.40	- 0.11	0.00	- 0.02	- 0.21
10	9	0.11	- 0.26	- 0.09	0.30	- 0.18	0.11	0.27	- 0.23	0.23	- 0.06	- 0.15	- 0.16

***), **) and *) = significance at 1%, 5% and 10% level of probability, respectively

Table 3. – SPEARMAN rank correlation coefficients between means and spatial neighbourhood correlations / coefficients of determination of the different entries for height.

		For spatial neighbourhood correlations											
field trial no.	age (in years)	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}
1	11	- 0.39*	- 0.37*	- 0.49**	- 0.33	- 0.44**	–0.39*	- 0.34*	- 0.44**	- 0.44**	0.33	0.25	0.36*
	13	- 0.52***	- 0.38*	- 0.44**	- 0.20	- 0.47**	–0.33	- 0.31	- 0.43**	- 0.33	0.45**	0.24	0.39*
	18	- 0.46**	- 0.19	- 0.48**	- 0.07	- 0.20	–0.12	- 0.16	- 0.20	- 0.14	0.39*	0.26	0.40*
	19	- 0.27	- 0.16	- 0.36*	- 0.02	- 0.28	–0.12	- 0.20	- 0.31	- 0.12	0.19	0.33	0.38*
	50	0.16	0.07	0.07	0.16	0.13	0.18	0.16	0.11	0.12	- 0.09	0.07	- 0.03
2	11	0.14	0.17	0.43	- 0.33	0.02	–0.33	- 0.26	- 0.10	- 0.24	- 0.43	- 0.33	- 0.40
3	9	- 0.13	- 0.25	0.14	0.48	- 0.13	0.03	0.79***	- 0.32	0.14	- 0.19	0.32	0.00
4	11	0.62**	0.08	0.16	- 0.28	- 0.01	–0.27	0.03	- 0.16	- 0.25	- 0.15	- 0.12	- 0.28
5	7	0.48	0.10	0.21	0.24	0.33	0.38	0.07	0.08	0.17	- 0.60	0.33	- 0.02
6	8	- 0.29	- 0.02	- 0.13	- 0.29	- 0.16	–0.32	- 0.40*	- 0.10	- 0.31	0.11	0.03	0.04
7	8	0.53**	0.63***	0.55**	0.52**	0.55**	0.54**	0.53**	0.55**	0.60**	0.12	0.12	0.05
8	10	0.03	- 0.10	0.08	- 0.09	- 0.06	–0.09	- 0.20	- 0.05	- 0.16	- 0.25	0.13	- 0.08
9	9	0.18	0.15	0.29	0.25	- 0.04	0.04	0.13	- 0.03	0.04	- 0.20	- 0.11	- 0.38
10	9	0.46*	0.05	0.34	0.25	- 0.04	0.18	0.30	0.02	0.25	- 0.48**	- 0.15	- 0.37

		For coefficients of determination of spatial neighbourhood correlations											
field trial no.	age (in years)	r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}
1	11	- 0.24	- 0.32	- 0.47**	- 0.25	- 0.35*	- 0.27	- 0.39*	- 0.38*	- 0.48**	- 0.23	- 0.30	- 0.40*
	13	- 0.53***	- 0.45**	- 0.47**	- 0.10	- 0.28	- 0.15	- 0.17	- 0.21	- 0.30	- 0.45**	- 0.53***	- 0.49**
	18	- 0.49**	- 0.33	- 0.56***	- 0.01	- 0.15	0.05	- 0.07	- 0.14	- 0.10	- 0.37*	- 0.54***	- 0.48**
	19	- 0.30	- 0.29	- 0.45**	- 0.06	- 0.28	0.03	- 0.01	- 0.38*	- 0.20	- 0.38*	- 0.60***	- 0.58***
	50	0.12	0.10	0.05	0.19	0.11	0.16	0.20	0.34	0.01	0.27	- 0.09	- 0.08
2	11	0.76**	0.12	0.43	- 0.38	- 0.45	- 0.52	- 0.40	0.19	- 0.26	0.76**	- 0.12	0.24
3	9	- 0.16	- 0.32	0.20	- 0.15	- 0.32	- 0.05	- 0.69**	- 0.47	- 0.04	0.09	- 0.43	0.07
4	11	0.34	- 0.16	- 0.27	- 0.02	- 0.29	0.07	- 0.09	- 0.35	0.05	- 0.17	0.00	- 0.21
5	7	0.48	0.24	0.07	0.24	0.33	0.38	0.07	0.08	0.17	- 0.29	0.31	- 0.10
6	8	- 0.25	-0.02	- 0.15	- 0.27	- 0.16	- 0.32	- 0.38*	- 0.10	- 0.30	0.11	- 0.21	0.02
7	8	0.62***	0.65***	0.74***	0.70***	0.52**	0.71***	0.71***	0.53**	0.77***	- 0.10	0.65**	0.26
8	10	- 0.12	- 0.25	- 0.07	- 0.13	- 0.24	- 0.09	- 0.18	- 0.30	- 0.16	- 0.02	- 0.36*	- 0.25
9	9	- 0.29	0.07	- 0.14	- 0.18	0.12	0.15	- 0.04	0.13	0.22	- 0.21	- 0.13	- 0.37
10	9	0.38	- 0.11	0.22	0.00	- 0.26	0.05	0.19	- 0.17	0.19	0.35	0.00	0.18

***), **) and *) = significance at 1%, 5% and 10% level of probability, respectively

means of the different entries are presented in *table 2* (diameter), *table 3* (height) and *table 4* (individual basal area).

In the subsequent sections the results for diameter (*Table 2*), height (*Table 3*) and individual basal area (*Table 4*) are discussed concisely with emphasis given to the significant SPEARMAN correlation coefficients only.

For diameter (Table 2)

For field trial no. 1 (= trial with measurements from age 11 up to age 50) the SPEARMAN rank correlation coefficients between the means of the entries and each of the spatial neighbourhood correlations r_1, r_2, ..., r_{12} are all nonsignificant ($-0.34 \leq$ SPEARMAN coefficients ≤ 0.28).

For the corresponding coefficients of determination (instead of the neighbourhood correlations themselves), however, a few of the SPEARMAN coefficients are significantly different from zero, but these significances exhibit no clear pattern and they should not be over-interpreted ($-0.58 \leq$ SPEARMAN coefficients $\leq$ 0.26).

For all spatial neighbourhood correlations r_1, r_2, ..., r_{12} as well as for the corresponding coefficients of determination too, none of the 72 SPEARMAN rank correlation coefficients for the measurements at the mature ages 42, 49 and 50 is statistically different from zero!

For field trials nos. 2 to 10 one obtains roughly similar results: Only a few significant SPEARMAN coefficients for some of the neighbourhood correlations ($-0.59 \leq$ SPEARMAN coefficients ≤ 0.71) and some more significances if one uses the coefficients of determination ($-0.65 \leq$ Spearman coefficients ≤ 0.52). In both cases, however, no clear and unique patterns can be observed.

The significant coefficients are assigned to trials 3, 5 and 6 (for the neighbourhood correlation coefficients) and to trials 3, 5, 6, 7 and 8 (for the coefficients of determination). For trials 2, 4, 9 and 10 no significant SPEARMAN coefficient has been observed (for both approaches).

In this paper, an advanced discussion of the numerical values of the SPEARMAN correlation coefficients from *table 2* is unnecessary since here we are only interested in the central question: Are there any clear and significant relationships between means and spatial neighbourhood correlations. For the trait diameter the answer is: No!

For height (Table 3)

For field trial no. 1 the SPEARMAN rank correlation coefficients between the means of the entries and each of the spatial neighbourhood correlations r_1, r_2, ..., r_{12} are significantly different from zero in a ratio of roughly one third ($-0.52 \leq$ SPEARMAN coefficients ≤ 0.45).

For the corresponding coefficients of determination (instead of the neighbourhood correlations themselves) one obtains quite similar results ($-0.60 \leq$ SPEARMAN coefficients ≤ 0.34). In

Table 4. – SPEARMAN rank correlation coefficients between means and spatial neighbourhood correlations / coefficients of determination of the different entries for individual basal area.

field trial no.	age (in years)	For spatial neighbourhood correlations											
		r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}
	11	- 0.15	- 0.09	- 0.23	- 0.21	- 0.11	- 0.14	- 0.26	- 0.08	- 0.13	0.03	0.13	0.11
	13	- 0.19	- 0.03	- 0.17	- 0.21	- 0.02	- 0.12	- 0.27	- 0.02	- 0.17	0.13	0.05	0.08
	18	- 0.31	- 0.01	- 0.23	- 0.24	0.01	- 0.21	- 0.29	- 0.02	- 0.19	0.24	0.09	0.16
1	19	- 0.27	0.04	- 0.27	- 0.19	0.00	- 0.12	- 0.24	- 0.04	- 0.15	0.22	0.07	0.18
	42	- 0.17	0.01	- 0.03	0.22	- 0.20	- 0.01	0.08	- 0.03	0.02	0.12	- 0.06	0.02
	49	- 0.14	0.12	0.03	0.07	- 0.09	0.03	0.04	0.05	0.00	0.06	- 0.15	0.01
	50	- 0.18	0.03	- 0.09	0.21	- 0.11	0.11	0.03	0.04	0.09	0.16	- 0.09	0.12
2	11	- 0.12	0.10	- 0.02	- 0.17	0.10	- 0.05	- 0.10	0.00	- 0.31	0.05	0.14	0.29
3	9	- 0.15	- 0.24	- 0.55*	- 0.09	- 0.12	- 0.34	- 0.08	- 0.26	- 0.46	0.34	0.57*	0.69**
4	11	0.12	0.01	0.10	0.33	0.02	0.07	0.18	0.11	0.09	- 0.02	0.11	0.23
5	7	- 0.21	- 0.35	- 0.35	- 0.17	- 0.05	- 0.19	- 0.20	0.04	- 0.02	0.06	0.11	0.12
6	9	- 0.40*	- 0.39*	- 0.45**	- 0.40*	- 0.43**	- 0.50**	- 0.36	- 0.44**	- 0.45**	0.18	0.18	0.15
7	9	0.34	0.24	0.34	0.35	0.17	0.30	0.31	0.18	0.28	- 0.22	- 0.11	- 0.17
8	10	- 0.17	- 0.17	- 0.17	- 0.22	- 0.22	- 0.15	- 0.22	- 0.12	- 0.12	- 0.05	0.06	- 0.01
9	9	- 0.13	- 0.07	- 0.09	- 0.21	- 0.20	- 0.17	- 0.06	- 0.23	- 0.23	0.01	- 0.25	- 0.26
10	9	- 0.27	- 0.12	- 0.33	- 0.25	- 0.14	- 0.18	- 0.26	- 0.02	- 0.32	- 0.12	0.20	0.11

field trial no.	age (in years)	For coefficients of determination of spatial neighbourhood correlations											
		r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9	r_{10}	r_{11}	r_{12}
	11	- 0.03	- 0.11	- 0.09	- 0.18	0.13	0.08	- 0.14	0.13	0.07	- 0.29	- 0.21	- 0.28
	13	- 0.15	- 0.07	- 0.11	- 0.35*	0.22	0.02	- 0.32	0.17	- 0.09	- 0.16	- 0.18	- 0.09
	18	- 0.41**	- 0.13	- 0.26	- 0.17	- 0.14	- 0.09	- 0.24	- 0.15	- 0.20	- 0.34	- 0.53***	- 0.48**
1	19	- 0.10	0.01	- 0.15	- 0.07	- 0.03	- 0.01	- 0.13	- 0.06	- 0.12	- 0.29	- 0.47**	- 0.47**
	42	0.17	0.15	0.03	- 0.20	0.05	- 0.11	- 0.14	- 0.02	0.20	0.12	0.17	- 0.02
	49	0.14	- 0.03	- 0.03	0.05	0.23	0.10	- 0.14	0.10	0.21	0.06	0.03	0.01
	50	0.18	0.10	0.09	0.00	0.10	0.09	- 0.08	- 0.04	0.11	0.16	0.13	0.12
2	11	0.12	- 0.10	0.02	0.17	0.45	0.19	0.02	- 0.40	0.38	0.05	0.14	0.29
3	9	0.30	- 0.61**	0.13	0.15	- 0.15	0.06	0.07	- 0.55**	- 0.31	0.00	- 0.29	0.19
4	11	0.00	- 0.20	- 0.24	0.15	- 0.17	0.09	0.28	- 0.14	0.08	- 0.07	0.08	0.20
5	7	- 0.17	- 0.35	- 0.35	- 0.11	0.01	- 0.17	- 0.14	0.13	0.02	- 0.27	0.09	0.04
6	9	- 0.47**	- 0.38*	- 0.44**	- 0.24	- 0.45**	- 0.32	- 0.23	- 0.39*	- 0.29	0.05	- 0.47**	- 0.25
7	9	0.50*	0 .17	0.39	0.50**	0.08	0.35	0.54**	0.16	0.39	0.01	- 0.28	0.12
8	10	- 0.33	- 0.32	- 0.40*	- 0.20	- 0.30	- 0.15	- 0.21	- 0.13	- 0.09	- 0.21	- 0.32	- 0.19
9	9	0.09	- 0.07	0.26	- 0.04	- 0.15	0.25	- 0.15	- 0.25	- 0.07	0.11	- 0.08	- 0.16
10	9	0.25	- 0.22	0.24	0.33	- 0.51**	0.27	0.27	- 0.35	0.17	- 0.27	- 0.03	- 0.31

***), **) and *) = significance at 1%, 5% and 10% level of probability, respectively

both cases, however, the significances exhibit no clear and cogent pattern and they should not be over-interpreted.

For all spatial neighbourhood correlations r_1, r_2, ..., r_{12} as well as for the corresponding coefficients of determination too none of the 24 SPEARMAN rank correlation coefficients for the measurements at the mature age 50 is statistically different from zero.

For both situations (neighbourhood correlations and coefficients of determination) the following rough tendency on time trends can be observed: Negative SPEARMAN rank correlations of intermediate numerical amount at the early stages of stand development and positive SPEARMAN rank correlations of very small numerical amount at the late = mature stage of stand development (age 50).

For field trials nos. 2 to 10 one obtains roughly similar results: Only a few significant SPEARMAN coefficients for some of the neighbourhood correlations ($-0.60 \leq$ SPEARMAN coefficients ≤ 0.79) and approximately the same number of significances if one uses the coefficients of determination ($-0.69 \leq$ SPEARMAN coefficients ≤ 0.77). In both cases, however, no clear and unique patterns can be observed.

The significant coefficients are assigned to trials 3, 4, 6, 7 and 10 (for the neighbourhood correlation coefficients) and to trials 2, 3, 6, 7 and 8 (for the coefficients of determination). For trials 5 and 9 no significant SPEARMAN coefficient has been observed (for both approaches).

The field trial with the most uniform correlation results is trial no. 7: For the spatial neighbourhood correlations r_1, r_2, ..., r_9 and for their coefficients of determination too one obtains highly significant positive SPEARMAN rank correlation coefficients of a similar numerical amount (0.52 to 0.63 for spatial neighbourhood correlations and 0.52 to 0.77 for their coefficients of determination). For trial no. 7 a clear relationship between means and spatial neighbourhood correlations exists. That means: The strength of the spatial neighbourhood correlation increases with increasing mean!

In general, however, for the trait height no clear and significant relationships between means and spatial neighbourhood correlations have been observed.

For individual basal area (Table 4)

The results must be, of course, quite similar to the results for diameter (*Table 2*): For field trial no. 1 (repeated measurements at different stages of stand development) the SPEARMAN rank correlation coefficients between the means of the entries and each of the spatial neighbourhood correlations r_1,

$r_2, \ldots, r_{12}$ are all nonsignificant ($-0.31 \le$ SPEARMAN coefficients ≤ 0.24). For the corresponding coefficients of determination, however, a few of the SPEARMAN coefficients are significantly different from zero, but these significances exhibit no clear and cogent pattern and they should not be over-interpreted ($-0.53 \le$ SPEARMAN coefficients ≤ 0.23).

For $r_1, r_2, \ldots, r_{12}$ as well as for the corresponding coefficients of determination none of the 72 SPEARMAN rank correlation coefficients for the measurements at the mature ages 42, 49 and 50 is statistically significant different from zero.

For field trials nos. 2 to 10 one obtains roughly similar results: Only a few significant SPEARMAN coefficients for some of the neighbourhood correlations ($-0.55 \le$ SPEARMAN coefficients ≤ 0.69) and for some of the coefficients of determination ($-0.61 \le$ SPEARMAN coefficients ≤ 0.54).

The most uniform results are obtained for trial no. 6 with negative SPEARMAN rank correlation coefficients for $r_1, r_2, \ldots, r_9$ (for both approaches).

In general, however, for the trait individual basal area too, no clear relationships between means and spatial neighbourhood correlations (or their coefficients of determination) were observed.

The preceding investigations on the relationships between spatial neighbourhood correlations and means are based on several simplifying assumptions. For a critical discussion of the limitations and restrictions of the numerical results of this paper imposed by these simplifications we refer to HÜHN and LANGNER (1995).

The discussion and interpretation of all results where the spatial neighbourhood correlation coefficients r_{10}, r_{11} and r_{12} are involved should be handled very cautiously: The discrete variable number of missing values does not fulfill the requirements for a common correlation analysis. In this study, the correlations r_{10}, r_{11} and r_{12} have been calculated incidentally in an only formal-descriptive point of view. They should not be over-interpreted. Of main interest are, therefore, the results which are related to the spatial neighbourhood correlations $r_1, r_2, \ldots, r_9$. Among them the correlations r_7, r_8 and r_9 are the most interesting ones. These coefficients are those neighbourhood correlations which are based on pairs of individual neighbouring trees while the remaining correlations are based on sums of neighbours or means of neighbours. These correlations r_7, r_8 and r_9 are, therefore, accessible to direct biological interpretations (competitive pressure by sharing common resources within the stand).

A dynamic description during stand development with an analysis of temporal changes and time trends of the SPEARMAN rank correlations between neighbourhood correlation coefficients and means of the different entries can be only carried out for trial no. 1 where successive measurements at several ages were available. The results for r_7, r_8 and r_9 are summarized in *table 5*. No detailed discussion of these results will be given in this paper. Here, we only point to 2 basic relationships:

1. The SPEARMAN rank correlation coefficients between spatial neighbourhood correlations r_7, r_8 and r_9 and means of the different entries change from negative values of small numerical amount at the early (=juvenile) stages of stand development up to slightly positive or zero correlations at the late (= mature) stages of stand development. That means: In advanced stages of stand development there exists no correlation between the level of the measurements (expressed by their mean) and the amount of spatial neighbourhood correlations. Relationships among the yields of competing neighbours are independent on the yield level!

2. With regard to the amount of the rank correlations (positive or negative) from *table 5*, for most cases one obtains: {height} ≥ {diameter} ≅ {individual basal area}.

For the SPEARMAN rank correlations between spatial neighbourhood correlations (or their coefficients of determination) and means one obtains no generally valid pattern for the 3 traits (height, diameter, individual basal area) (*Tables 2* to *4*). The results for the different trials are also quite different.

For the comparison height-diameter, for example, one obtains positive SPEARMAN correlation coefficients for $r_1, r_2, \ldots,$

Table 5. – SPEARMAN rank correlation coefficients between the neighbourhood correlations r_7, r_8 and r_9 [= correlation between subject tree and 1 direct neighbour, 1 diagonal neighbour and 1 neighbour (direct or diagonal)] of the different entries and their means for trial no. 1.

		stages of stand development = ages (in years)						
	trait	11	13	18	19	42	49	50
For r_7	diameter	-0.27	-0.31	-0.32	-0.21	0.11	0.03	0.07
	height	-0.34	-0.31	-0.16	-0.20	-	-	0.16
	basal area	-0.26	-0.27	-0.29	-0.24	0.08	0.04	0.03
For r_8	diameter	-0.06	0.04	0.02	-0.04	-0.02	0.07	0.09
	height	-0.44	-0.43	-0.20	-0.31	-	-	0.11
	basal area	-0.08	-0.02	-0.02	-0.04	-0.03	0.05	0.04
For r_9	diameter	-0.15	-0.17	-0.17	-0.12	0.00	0.01	0.09
	height	-0.44	-0.33	-0.14	-0.12	-	-	0.12
	basal area	-0.13	-0.17	-0.19	-0.15	0.02	0.00	0.09

Table 6. – SPEARMAN rank correlation coefficients between the neighbourhood correlations / coefficients of determination of the different entries and their means for trial no. 7.

	For neighbourhood correlations			For coefficients of determination		
	height	diameter	individual basal area	height	diameter	individual basal area
r_1	0.53	0.21	0.34	0.62	0.41	0.50
r_2	0.63	0.28	0.24	0.65	0.29	0.17
r_3	0.55	0.23	0.34	0.74	0.39	0.39
r_4	0.52	0.21	0.35	0.70	0.52	0.50
r_5	0.55	0.19	0.17	0.52	0.22	0.08
r_6	0.54	0.17	0.30	0.71	0.36	0.35
r_7	0.53	0.21	0.31	0.71	0.52	0.54
r_8	0.55	0.13	0.18	0.53	0.16	0.16
r_9	0.60	0.16	0.28	0.77	0.31	0.39

Table 7. – SPEARMAN rank correlation coefficients between the neighbourhood correlations / coefficients of determination of the different entries and their means for trial no. 6.

	For neighbourhood correlations			For coefficients of determination		
	height	diameter	individual basal area	height	diameter	individual basal area
r_1	-0.29	-0.36	-0.40	-0.25	-0.45	-0.47
r_2	-0.02	-0.30	-0.39	-0.02	-0.30	-0.38
r_3	-0.13	-0.35	-0.45	-0.15	-0.42	-0.44
r_4	-0.29	-0.35	-0.40	-0.27	-0.35	-0.24
r_5	-0.16	-0.36	-0.43	-0.16	-0.38	-0.45
r_6	-0.32	-0.38	-0.50	-0.32	-0.41	-0.32
r_7	-0.40	-0.39	-0.36	-0.38	-0.32	-0.23
r_8	-0.10	-0.35	-0.44	-0.10	-0.29	-0.39
r_9	-0.31	-0.38	-0.45	-0.30	-0.39	-0.29

Table 8. – Ranges of the SPEARMAN rank correlation coefficients between the neighbourhood correlations / coefficients of determination of the different entries and their means.

	For neighbourhood correlations			For coefficients of determination		
	height	diameter	basal area	height	diameter	basal area
r_1	-0.39...0.62	-0.41...0.21	-0.40...0.34	-0.29...0.76	-0.45...0.41	-0.47...0.50
r_2	-0.37...0.63	-0.43...0.28	-0.39...0.24	-0.32...0.65	-0.43...0.29	-0.61...0.17
r_3	-0.49...0.55	-0.46...0.23	-0.55...0.34	-0.47...0.74	-0.52...0.39	-0.44...0.39
r_4	-0.33...0.52	-0.35...0.33	-0.40...0.35	-0.38...0.70	-0.35...0.52	-0.24...0.50
r_5	-0.44...0.55	-0.36...0.31	-0.43...0.17	-0.45...0.52	-0.62...0.22	-0.51...0.45
r_6	-0.39...0.54	-0.38...0.17	-0.50...0.30	-0.52...0.71	-0.41...0.36	-0.32...0.35
r_7	-0.40...0.79	-0.39...0.23	-0.36...0.31	-0.69...0.71	-0.36...0.52	-0.23...0.54
r_8	-0.44...0.55	-0.43...0.30	-0.44...0.18	-0.47...0.53	-0.65...0.16	-0.55...0.16
r_9	-0.44...0.60	-0.59...0.16	-0.46...0.28	-0.48...0.77	-0.51...0.31	-0.31...0.39
r_{10}	-0.60...0.33	-0.16...0.47	-0.22...0.34	-0.29...0.76	-0.33...0.12	-0.29...0.11
r_{11}	-0.33...0.33	-0.27...0.42	-0.25...0.57	-0.43...0.65	-0.30...0.05	-0.47...0.14
r_{12}	-0.40...0.36	-0.24...0.71	-0.26...0.69	-0.40...0.26	-0.27...0.43	-0.31...0.29

r_9 (and for their corresponding coefficients of determination too) for trial no. 7 with substantially stronger correlations for height than for diameter (for both approaches) (*Table 6*).

For trial no. 6, however, one obtains negative SPEARMAN correlation coefficients for r_1, r_2, ..., r_9 (and for their corresponding coefficients of determination too) and in this case the correlations are stronger for diameter than for height (*Table 7*).

The results for these 2 selected trials from *tables 6* and *7* indicate the substantial differences of the correlations for the different trials. These field trials represent a wide range of environmental conditions (HÜHN and LANGNER, 1992). The contrasting results for the individual trials, therefore, reflect the sensitivity of the correlations between spatial neighbourhood correlations and means with regard to varying environmental conditions. To give some impression on the amount of these variabilities the ranges of the SPEARMAN rank correlations have been summarized in *table 8* for trials 2 to 10 and, additionally, for the first measurement of trial no. 1 which is approximately comparable in its age to the ages of the other trials. The ranges of the SPEARMAN correlation coefficients for these trials are considerably large:

- 0.60 .... 0.79	(height)	For neighbourhood correlations
- 0.59 .... 0.71	(diameter)	
- 0.55 .... 0.69	(basal area)	

- 0.69 .... 0.77	(height)	For coefficients of determination
- 0.65 .... 0.52	(diameter)	
- 0.61 .... 0.54	(basal area)	

To get some deeper insight into these complex relationships a more refined analysis must be carried out for the correlation results of each individual trial separately. But, such a sophisticated analysis is beyond the scope of this paper.

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These references are mentioned in this paper. An extensive list of further references is given in HÜHN and LANGNER (1995).