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Height growth of some interracial hybrids of norway spruce using selected trees of a north and a central european provenance with special regard to between-plot-competition[1])

By M. Hühn[2]) and H.-J. Muhs[3])

Summary

7 crossings between selected trees of the provenances Sundmo (Sweden) and Westerhof (Germany) were done in 1954. Field trials were established in 1959 using these interracial hybrid progenies together with the open pollinated progenies of the parent trees (10 at a total). Height growth has been measured at different ages (from 5 to 17 years).

The results showed a superiority of the open pollinated progenies from Westerhof (W-progenies) at all locations and at all ages, while the open pollinated progenies from Sundmo (S-progenies) are inferior, and the hybrid progenies are of approximately intermediate height growth. From age 5 to age 17 the hybrid progenies increased their relative height growth from about 60% up to 80% compared to that of the W- progenies (= 100%). Thus the increment of height growth was higher than would be expected from exactly intermediate growth patterns of the hybrid progenies. A trend of an increasing increment of height growth was found, which at the age 17 was still evident. In the field trials at high elevation this trend was very strong. Here the increment of height growth of the hybrid progenies reached or even surpassed that of the W-progenies.

The results were in close agreement with those of Swedish investigations. It seems that interracial hybrids may be of some interest for sites at high elevations.

Key words: Norway spruce, interracial hybrids, height growth

Zusammenfassung

Sieben Kreuzungen zwischen selektierten Bäumen der Provenienz Sundmo (Schweden) und Westerhof (Deutschland) wurden 1954 durchgeführt. 1959 wurden Feldversuche angelegt mit diesen Zwischen-Rassen-Hybridkommenschaften zusammen mit den freiabgeblühten Nachkommenschaften der Elternbäume (insgesamt 10). Die Höhen wurden im Alter von 5 bis 17 Jahren gemessen.

Die Ergebnisse zeigten eine Überlegenheit der freiabgeblühten Nachkommenschaft von Westerhof (W-Nachkommenschaft) auf allen Standorten in jedem Alter, während die freiabgeblühten Nachkommenschaften von Sundmo (S-Nachkommenschaften) unterlegen waren und die Hybridnachkommenschaften annäherungsweise intermediäres Höhenwachstum zeigten. Im Alter von 5 bis 17 Jahren steigerten die Hybridnachkommenschaften ihr relatives Höhenwachstum von rund 60 auf 80% im Vergleich zu dem Höhenwachstum der W-Nachkommenschaften (= 100%). Daraus ergab sich, daß der Höhenzuwachs der Hybridnachkommenschaften größer war als der, der bei exakter intermediärer Vererbung der Anlage Höhenwachstum erwartet werden konnte. Ein Trend des zunehmenden Höhenzuwachses bei den Hybridnachkommenschaften wurde gefunden, der im Alter 17 noch anhielt. Gerade in den Feldversuchen der hohen Höhenlage war dieser Trend sehr deutlich. Hier erreichte der Höhenzuwachs der Hybridnachkommenschaften den der Westerhöfer Nachkommenschaften oder übertraf diese sogar.

Die Ergebnisse stimmten gut mit denen schwedischer Untersuchungen überein. Es scheint, daß die Zwischen-Rassen-Hybriden für Standorte in Höhenlagen Bedeutung haben können.

Introduction

Scandinavian and german forest tree breeders have been doing interracial hybridization in Norway spruce *(Picea*

Table 1. — Description of the location of the six trials.

Location of trials

location	latitude (north)	longitude (east)	altitude (m)
Furtwangen	48° 05'	8° 09'	1111
Schotten	50° 33'	9° 13'	650
Oderhaus	51° 41'	10° 33'	620
Altenau	51° 49'	10° 29'	870
Meppen	52° 48'	7° 18'	28
Trittau	53° 39'	10° 16'	50

Table 2. — Mean heights in cm according to the six locations and the different ages. Mean heights are pooled over all open pollinated progenies at Sundmo (S) and Westerhof (W), respectively, as well as over all hybrids (S × W).

Location	5	6	7	9	12	15	17
Furtwangen							
S	16.5	-	-	34.9	65.9	115.0	167.1
S x W	26.1	-	-	55.7	108.1	188.2	271.2
W	41.3	-	-	69.1	139.1	246.8	355.2
Schotten							
S	16.3	20.5	-	54.6	107.9	190.4	262.8
S x W	24.6	32.1	-	91.1	191.7	361.5	491.2
W	38.0	43.6	-	112.4	240.8	461.0	611.9
Oderhaus							
S	14.6	-	-	51.0	104.7	210.2	259.6
S x W	21.1	-	-	68.3	150.4	309.6	431.8
W	36.9	-	-	105.0	224.9	422.4	543.7
Altenau							
S	16.3	-	-	30.6	44.4	73.5	94.1
S x W	22.8	-	-	40.0	59.3	95.4	125.5
W	38.2	-	-	49.2	63.8	96.3	128.6
Meppen							
S	14.9	-	29.5	51.1	95.5	127.1	160.5
S x W	21.4	-	39.9	76.2	156.9	241.1	316.8
W	38.6	-	66.6	119.6	242.9	376.2	454.3
Trittau							
S	-	22.1	33.9	66.3	154.2	-	-
S x W	-	30.2	49.3	99.7	243.6	-	-
W	-	49.1	83.4	160.1	352.8	-	-

abies (L.) KARST.) for 25 years (LANGNER 1954; NILSSON 1958, 1964, 1974). Their aim has been to combine the generally more vigorous growth of certain central european spruce provenances with the frost hardiness of the north european spruce provenances, and of course, looking for some heterosis effects in growth. For Sweden at the latitude 59°N and farther north NILSSON (1973) reported superior height growth of the hybrids compared to central- and north european provenances, while at the latitude 56°N the central european progenies were superior and the hybrids showed some intermediate height growth. LANGNER (1954) found exactly intermediate height growth of interracial hybrids of central- and north european spruce at nursery age.

In 1954 LANGNER[4]) and STEFANSSON[5]) started a crossing program on this subject, results from which will be reported here. Unfortunately the mating design has been rather incomplete. But, at that time — 6 years after founding the Institute of Forest Genetics and Forest Tree Breeding at Schmalenbeck[6]) — it was somewhat of a pioneer effort on the international cooperation level.

In this paper height growth in the first 17 years is shown with special regard to the development of the hybrid progenies compared with open pollinated progenies from parent trees.

Materials and Methods

In 1954 crossings between selected trees of Norway spruce *(Picea abies* (L.) KARST.) from the provenance Sundmo (Middle-Sweden at about 63° north) and the provenance Westerhof (North Germany at about 52° north latitude) were done at Sundmo. 6 selected trees of the provenance Sundmo were pollinated with pollen of 4 trees of the provenance Westerhof, resulting in 7 hybrid progenies (in *Table 2* and *3* designated S × W). Reciprocal crosses were not made. From the mother trees in Sundmo as well as in Westerhof the open pollinated seed was collected (designation S and W respectively). Three additional progenies from certain crosses were included in the experiment, but they will not be included in the evaluation and discussion in this paper.

Sowing out was done in the nursery at Schmalenbeck in 1955 and six field trials were established in 1959. The locations with their geographic coordinates are listed in *Table 1*. Attention should be paid to the different altitudes.

The experimental design is a 4 × 5 rectangular lattice with 3 replications (plan 10.11 of COCHRAN and COX, 1957).

Table 3. — Mean heights in cm at age 17 of the 17 progenies at five locations. Number in brackets are ranking numbers starting with the lowest number for the progeny with the best height growth (S = Sundmo, W = Westerhof, S × W = hybrids).

Progeny		Furtwangen		Schotten		Oderhaus		Altenau		Meppen	
	1	134.5	(16)	222.5	(17)	294.0	(15)	93.7	(14)	140.5	(14)
	2	162.5	(15)	231.8	(15)	283.1	(16)	105.6	(11)	123.9	(16)
S	3	182.1	(13)	317.0	(13)	308.6	(14)	116.3	(9)	140.1	(15)
	4	162.6	(14)	249.6	(14)	256.7	(17)	85.4	(15)	147.2	(13)
	5	125.6	(17)	227.9	(16)	340.5	(12)	78.8	(17)	111.3	(17)
	6	235.2	(10)	328.0	(12)	334.4	(13)	85.0	(16)	300.2	(10)
	1 x 14	312.6	(5)	456.3	(9)	414.5	(9)	116.9	(8)	232.8	(12)
	2 x 16	276.9	(8)	520.2	(6)	419.3	(8)	153.4	(2)	350.0	(7)
	3 x 15	198.7	(12)	479.3	(8)	403.1	(10)	96.3	(13)	322.6	(9)
S x W	4 x 14	303.2	(7)	613.0	(3)	535.3	(3)	144.5	(3)	357.7	(6)
	5 x 16	230.1	(11)	432.5	(11)	359.4	(11)	125.5	(5)	330.2	(8)
	5 x 17	247.1	(9)	455.4	(10)	430.0	(7)	99.7	(12)	249.6	(11)
	6 x 15	330.1	(4)	481.9	(7)	461.0	(6)	142.4	(4)	374.8	(5)
	14	337.6	(3)	627.9	(2)	534.9	(4)	124.6	(6)	422.7	(3)
	15	310.0	(6)	547.4	(5)	548.0	(2)	111.5	(10)	418.4	(4)
W	16	362.8	(2)	608.7	(4)	497.0	(5)	120.3	(7)	540.8	(1)
	17	410.5	(1)	663.8	(1)	594.9	(1)	158.0	(1)	435.3	(2)

The square plots contain 36 trees planted at a 1.5 × 1.5 m spacing except at Trittau where spacing is 0.9 × 0.9 m.

Height growth was observed at the age of 5, 9, 12, 15 and 17 years. Additional measurements at age 6 or 7 were done at some locations (see Table 2). For Trittau some measurements are missing.

Disregarding the incomplete block structure evaluation was made in the form of a randomised block design. Since visual inspection of the trials indicated competition effects between plots, HÜHN (1974, 1976) carried out the analysis of variance both using data of the total plot (36 trees) and data of the interior plots (16 trees). He found that: Total variance increases using interior plot data compared to using total plot data. Further the variance component for treatments decreases and the experimental error increases. Thus the use of interior plot data resulted in fewer statistically significant differences in treatment comparison. HÜHN (1974) concluded that total plot data are biased due to competition between plots. Thus for the present paper the interior plot means have been used.

The development of height growth of single provenance hybrids is compared with that of the open pollinated progenies of the parent trees. Finally all hybrid progenies are grouped and the development of height growth is compared with the mean of all Westerhöfer progenies.

Results

The best height growth occured at the Trittau location. The Altenau location, with a very poor, stony soil has by far the lowest overall height growth.

If the means of the three groups are pooled over all locations (see Fig. 2) the Westerhöfer progenies generally have the best height growth, while Sundmo progenies are growing very slowly. The height growth of the hybrid group is more or less intermediate.

Going into more detail it can be shown that some hybrid progenies have equal or even better height growth than the open pollinated progenies of the best parent, e.g. hybrid progeny S × W (4 × 14) compared with W 14 at Oderhaus and Altenau, S × W (6 × 15) compared with W 15 at Furtwangen and Altenau, and S × W (2 × 16) compared with W 16 at Altenau (see Table 3). But there is no hybrid progeny with less height growth than the open pollinated progeny of the Sundmo parent (S) at age 17.

Ranks of the mean height of the progenies remain relatively constant for each of the different locations (see Table 3). Thus SPEARMAN's coefficient of rank correlation is very high (about 0.85 to 0.92), except for location Altenau (0.67 to 0.75). Furthermore the interaction between progenies × locations is relatively small and constant over years (about 7—10%). More detailed information about results of the analysis of variance and significance tests, which are in agreement to those presented here are given elsewhere (HÜHN 1974, 1976).

The best progeny at all locations except at Meppen is W 17. This progeny is significantly better (at the 5% level) to about 80% of all progenies at all locations at age 17. The best hybrid progeny is S × W (4 × 14) which occupies the first rank of the hybrid progenies at locations Schotten, Oderhaus and Altenau, second at Meppen and third at Furtwangen.

Looking at the development of height growth during the years from 5 to 17 there can be observed a most interesting tendency of the hybrid progenies to increase height growth compared to the open pollinated progenies of the best parent (W). This is evident if mean height growth of all S × W progenies are calculated as percentage of the resp. mean height growth of all W progenies (see Figure 1). At age 5 average height growth was about 60% (roughly) for S × W progenies. This percentage increased up to roughly 80% at age 17. The Altenau location is an exception in this case. Here the height growth of the hybrid progenies is nearly equal to the height of the W progenies.

Discussion

The wide spread opinion that interracial hybrids of north- and centraleuropean Norway spruce are more or less of intermediate growth is proved once more. The results show a clear superiority of the Westerhöfer progenies (W), although some hybrid progenies are equal or better in height growth than their respective W-progenies. This demonstrates that specific combining ability seems to be of importance (NILSSON 1967, 1970; NILSSON and ANDERSSON 1969).

A recent result is the tendency of the hybrid progenies to increase their growth rate with increasing years.

In Figure 2 where the means are pooled over groups and locations, it can be seen that the mean height of the hybrids is up to age 9 below the midpoint between the heights of the open pollinated progenies. But for age 12, 15 and 17 it is above the midpoint with an increasing tendency. An extrapolation of this trend up to the rotation age would be
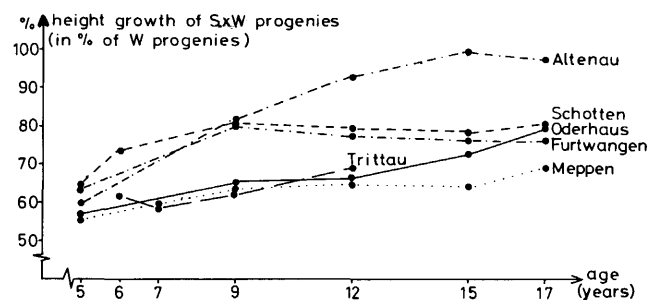

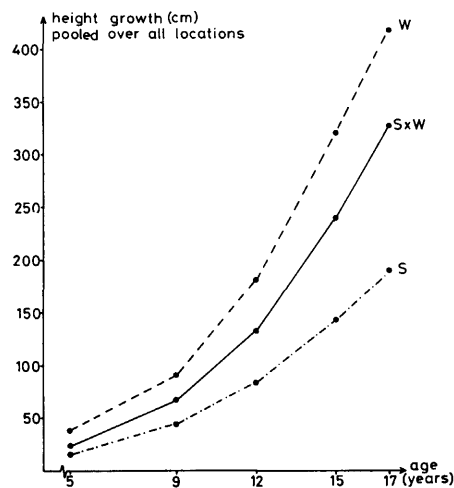Figure 1. — Height growth of S × W progenies (in % of W progenies) for the six locations in the different years.

Figure 2. — Height growth (in cm) of W, S × W and S pooled over all locations in the different years.

of great interest, but it cannot be calculated from this data. The trials should be observed for additional time.

Reasons for this trend are not known. Although this trend can be observed at all locations, there seem to be some differences (see *Table 2* and *Figure 1*). Trials at a high elevation with a severe climate, e.g. the Altenau location show the trend clearly. Here relative height growth of S × W progenies compared with the W progenies develops from about 60% at age 5 up to about 98% at age 17. In absolute terms of height growth this means that the increment after field planting of the hybrid progenies is 102.7 cm and that of the W progenies only 90.4 cm. Thus height growth of the hybrid progenies is better than that of the W progenies. Looking at the trials at low elevation the trend of the hybrid progenies to increase height growth is not as clear (see location of Meppen in *Table 2* and *Figure 1*). Height growth development at other locations (Furtwangen, Schotten) show intermediate trends.

From these results we can conclude that interracial hybrids between trees of the procenances of Sundmo and Westerhof may be of interest only for sites at high elevations, where the fast growing progenies from Westerhof cannot be grown. Further testing should be done to determine if these hybrids are equal or better in growth compared to some local or other provenances suited for high elevations.

Swedish colleagues have some more experience in interracial hybridization. They found better height growth of the hybrids compared to the open pollinated progenies of both parent trees (NILSSON 1973, ERICSSON 1975) at the latitude of 59° north and farther north. If growth conditions in the far north and at high elevations are considered to be similar in some major aspects, these findings and the results presented here are in agreement.

Appendix

In all previous investigations of the present paper only the 4 × 4 interior of each 6 × 6 plot had been used — that means: The progeny-means had been computed by eliminating the plants at the borders of each 6 × 6 plot. In this way the possible bias caused by the competitive effects at the borders of the plots can be avoided for the most part.

But in almost all practical situations this elimination of the competitive border-effects will not be done, because the total plots are measured and analysed. Therefore it would be of interest to know whether or not the previous results are changed by using the total plot means.

In *Table 4* mean heights (in cm) are given for S, W and S × W and the different ages for the "without 'between-plot-competition' analysis" ('without') (using the 4 × 4 interior of each 6 × 6 plot) and the "with 'between-plot-competition' analysis" ('with') (using the total 6 × 6 plot). Mean heights are pooled over all locations (except 'Trittau', see: Materials and Methods) and over all open pollinated progenies at Sundmo (S) and Westerhof (W) respectively as well as over all hybrids (S × W).

These results of *Table 4* turn out to be in good accordance with the results of *Figure 2*.

Table 4. — Height growth (in cm) (pooled over all locations) for S, W and S × "W, for the without 'between-plot-competition' analysis" and the "with 'between-plot-competition' analysis".

	Age	Without "between-plot-competition" (see figure 2)	With "between-plot-competition"	|difference| (in %)
S	5	15.7	16.7	6.4
	9	44.4	45.4	2.3
	12	83.7	86.1	2.9
	15	143.2	147.3	2.9
	17	188.8	202.3	7.2
W	5	38.6	39.0	1.0
	9	91.1	91.5	0.4
	12	182.3	182.5	0.1
	15	320.5	318.9	0.5
	17	418.7	418.6	0.0
SxW	5	23.2	24.3	4.7
	9	66.2	68.1	2.9
	12	133.3	137.2	2.9
	15	239.2	244.3	2.1
	17	327.3	331.3	1.2

Table 5. — Mean heights (in cm) according to the six locations and the different ages for the "with 'between-plot-competition' analysis" ('with') and the absolute values of their differences (in %) in relation to the corresponding results of the "without 'between-plot-competition' analysis" (= 100 %) (table 2).
Mean heights are pooled over all open pollinated progenies at Sundmo (S) and Westerhof (W) respectively as well as over all hybrids (S × W).

	Age 5		Age 9		Age 12		Age 15		Age 17	
Location	'with'	|diff| (%)	'with'	|diff| (%)	'with'	|diff| (%)	'with'	|diff| (%)	'with'	|diff| (%)
Furtwangen										
S	17.1	3.6	35.9	2.9	68.1	3.3	117.2	1.9	174.3	4.3
SxW	26.5	1.5	54.9	1.4	109.0	0.8	190.1	1.0	273.6	0.9
W	42.2	2.2	68.1	1.4	136.4	1.9	236.5	4.2	340.4	4.2
Schotten										
S	16.5	1.2	54.4	0.2	108.5	0.6	189.4	0.5	268.2	2.1
SxW	24.5	0.4	89.5	1.8	188.9	1.5	351.6	2.7	483.0	1.7
W	38.2	0.5	114.4	1.8	243.6	1.2	456.9	0.9	605.3	1.1
Oderhaus										
S	15.7	7.5	52.5	3.1	107.9	3.1	219.4	4.4	300.6	15.8
SxW	23.4	10.9	75.9	11.1	165.8	10.2	334.3	8.0	452.9	4.9
W	37.1	0.5	105.2	0.2	222.2	1.2	419.1	0.8	550.3	1.2
Altenau										
S	18.0	10.4	31.4	2.6	43.9	1.1	71.4	2.9	93.0	1.2
SxW	24.2	6.1	41.0	2.5	59.6	0.5	95.9	0.5	125.3	0.2
W	38.6	1.0	50.7	3.0	67.3	5.5	104.0	8.0	134.9	4.9
Meppen										
S	16.4	10.1	52.9	3.5	102.0	6.8	139.1	9.4	175.3	9.2
SxW	22.8	6.5	79.2	3.9	162.9	3.8	249.7	3.6	321.9	1.6
W	38.8	0.5	119.1	0.4	242.9	0.0	378.0	0.5	462.0	1.7

	Age 6		Age 7		Age 9		Age 12	
Location	'with'	|diff| (%)	'with'	|diff| (%)	'with'	|diff| (%)	'with'	|diff| (%)
Trittau								
S	22.3	0.9	35.4	4.4	69.9	5.4	160.9	4.4
SxW	30.4	0.7	50.2	1.8	101.8	2.2	245.4	0.7
W	49.3	0.4	83.3	0.1	160.7	0.4	355.2	0.7

Table 6. — Mean heights (in cm) at age 17 of the 17 progenies at five locations for the "with 'between-plot-competition' analysis". Numbers in brackets are ranking numbers starting with the lowest number for the progeny with the best height growth and absolute values of the differences (in %) between "with' and 'without' ≅ 100%) (S = Sundmo, W = Westerhof, S × W = hybrids).

Location of trials

Progeny	Furtwangen 'with'	rank	|diff| (%)	Schotten 'with'	rank	|diff| (%)	Oderhaus 'with'	rank	|diff| (%)	Altenau 'with'	rank	|diff| (%)	Meppen 'with'	rank	|diff| (%)
1	148.0	16	10.0	204.2	17	8.2	280.5	17	4.6	94.7	13	1.1	162.7	14	15.8
2	154.8	15	4.7	236.8	16	2.2	281.3	16	0.6	92.7	14	12.2	131.5	17	6.1
3	180.5	13	0.9	316.8	13	0.1	313.7	13	1.7	110.6	10	4.9	155.9	15	11.3
4	167.0	14	2.7	242.4	15	2.9	300.7	15	17.1	89.8	15	5.2	164.9	13	12.0
5	144.4	17	15.0	249.8	14	9.6	319.2	12	6.3	83.9	17	6.5	149.0	16	33.9
6	250.9	10	6.7	359.2	12	9.5	308.3	14	7.8	86.1	16	1.3	287.8	10	4.1
1x14	299.8	6	4.1	447.9	10	1.8	464.0	6	11.9	129.9	6	11.1	236.3	12	1.5
2x16	270.8	8	2.2	486.3	7	6.5	435.5	9	3.9	143.0	3	6.8	354.2	7	1.2
3x15	217.9	12	9.7	472.9	8	1.3	418.5	10	3.8	97.9	12	1.7	310.9	9	3.6
4x14	290.8	7	4.1	618.7	2	0.9	532.7	4	0.5	147.0	2	1.7	365.2	6	2.1
5x16	239.6	11	4.1	448.8	9	3.8	409.9	11	14.1	124.5	7	0.8	324.5	8	1.7
5x17	263.0	9	6.4	418.6	11	8.1	447.5	8	4.1	104.3	11	4.6	264.8	11	6.1
6x15	333.2	3	0.9	488.2	6	1.3	462.3	7	0.3	130.6	5	8.3	397.2	5	6.0
14	327.1	4	3.1	617.9	3	1.6	533.1	3	0.3	135.7	4	8.9	431.9	3	2.2
15	306.0	5	1.3	532.6	5	2.7	556.8	2	-1.6	112.6	9	1.0	416.6	4	0.4
16	340.2	2	6.2	612.8	4	0.7	499.4	5	0.5	124.4	8	3.4	541.4	1	0.1
17	388.2	1	5.4	658.1	1	0.9	612.0	1	2.9	166.8	1	5.6	458.0	2	5.2

The differences between 'without' and 'with' (always in relation to 'without' ≅ 100%) are 0%—7% — where the smallest differences are found for W (0%—1%), largest differences for S (2%—7%) and medium differences for S × W (1%—5%) (Table 4).

For all the groups (S, W, and S × W) the mean heights for 'with' are larger than for 'without' in almost all situations. Therefore the absolute values of the mean heights are unimportantly changed indeed, while the relations between S, W and S × W are hardly affected by the between-plot-competition.

The separate results of the different locations are given in Table 5.

The differences between 'with' (Table 5) and 'without' (Table 2) (again in relation to 'without' ≅ 100%) are in the range of 0%—16%. The lowest differences are found for the locations Schotten, Trittau and Furtwangen, while Oderhaus, Meppen and Altenau show the highest differences. For a more detailed separate consideration and analysis of the three groups S, W and S × W we refer to Table 5.

Finally we will discuss the results of the 'with'-analysis in correspondance to Table 3 (Table 6). With this separate consideration of the single progenies at the different locations for the age 17 (time of the last measurement) in Table 6 even larger differences between the two analyses 'with' and 'without' are expectedly obtained. These differences are in the range of 0%—34%.

In spite of these differences, which are especially large in some situations the rank-orders of the progenies are nearly identical for the two analyses 'with' and 'without' for each location. The corresponding Spearman-rank-correlation-coefficients are extremely high: 0.96—1.00.

Therefore single progeny-comparisons can be extremely affected and biased by nonconsidering the competitive effects at the borders of the plots. While this is not true for the rank-orders of the progenies, which remains unchanged by nonconsidering the between-plot-competition.

For a more detailed separate consideration and analysis of the results in the three groups S, W and S × W we refer to Table 6. Extensive studies of these two analyses 'with' and 'without' as well as their effect on: comparison of progeny-means, statistical tests of significance, progeny-rank-orders, estimation of variance-components etc. have been discussed in detail in Hühn (1974).

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