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Yield and competition in barley variety mixtures

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Abstract. Competition between spring barley varieties and yield performance of two-, three- and four-variety mixtures were studied in two replacement series field experiments. In the first experiment, repeated in three successive years (1983—85) the components were the six-row varieties Agneta, Arra, Hja-673 and Pomo. In the second experiment (1984), including two nitrogen doses (50 and 100 kgN/ha), both six-row (Agneta, Pomo) and two-row (Ida, Kustaa) varieties were used.

Arra in the first and Agneta in the second experiment were the most competitive varieties. The results suggested that the fast growth of Arra at the beginning promoted its competitive ability. Increase in available nitrogen usually strengthened the competitiveness of Agneta. The observed competitive differences between varieties were not related to the earliness of a variety, neither to the morphological characters (two- and six-row varieties) nor to the grain yield of a variety grown alone. The competitive ability was not always a stable character, the dominant-suppression relationship varying from one environment to another (e.g. growing season, nitrogen dose).

The observed overyielding was not statistically significant. The ratio of actual to expected yield and the relative yield total of several mixtures exceeded slightly one. As a conclusion, the yield advantage of mixtures was marginal. As a rule, the mixtures were not more stable than monocultures as determined by the coefficient of variation. However, the yield of some mixtures varied less than the yield of the most stable monoculture.

Index words: Competition, yield, barley, mixture

INTRODUCTION

Mixtures of field crops are still extensively grown in traditional agriculture, but where more mechanized methods are used, monocultures are more common. The plant communities with some degree of genotypic heterogeneity may have advantages over pure stands. These alleged advantages have included one or more of the following: higher yields, lower variability of yield from season to season, an even distribution of production over the growth period, less susceptibility to disease or lodging, and an improved quality of the crop product (Trenbath 1974).

Also growing of variety mixtures, multilines or bulk hybrids instead of pure line varieties has been proposed as a means of obtaining higher and more stable yields. The mixture represents an obvious agronomic advantage in cases where the yield of the mixture exceeds the yield of the highest-yielding component grown in pure stand but in most cases the yields of the mixtures have been reported to be about the same as or slightly higher than that of the weighted mean of their components (Simmonds 1962, Allard and Adams 1969, Clay and Allard 1969, Sandfaer 1970, Blijenburg and Sneep 1975, Lang et al. 1975, Eisenberg 1980, Nitzshe and Hesselbach 1983, Aufhammer et al. 1984, Baker and Briggs 1984, Harrabi et al. 1986, Houmoller et al. 1986, Karjalainen and Hiivola 1987, McDonald et al. 1988, Aufhammer and Stutzel 1989).

In many experiments on varietal mixtures the yield advantage is not thoroughly assessed. This is because an analysis performed according to the de Wit model (relative yield total) (de Wit 1960, de Wit and van den Berg 1965) is in most cases impossible because only the total yield of a mixture is measured. In mixtures with relative yield total values (RYT) or land equivalent ratio values (LER) equal to unity where the highest-yielding component is the strongest competitor, the yield of the mixture will exceed the weighted mean of the components. However, this does not involve an agronomic advantage (Willey 1979, 1985). Only when RYT is greater than one is an agronomic advantage obvious.

The replacement series experiments described here were made to test the hypothesis that mixtures of different spring barley varieties contrasted in terms of maturity, and morphological properties would yield more than the same varieties grown separately, possibly through more efficient use of resources. Different ways (see above) to evaluate the yield advantage of mixtures are to be considered. Besides the agronomically important yields also competitional interactions among barley varieties are elucidated.

MATERIALS AND METHODS

Two experiments were carried out between 1983 and 1985. Experiment 1 was repeated in three successive years. Experiment 2 was carried out once in 1984. The trials were located on the Viikki trial field, Helsinki University (60° 13′, 25° 00′E). The soil pH varied from 5.4 to 5.8 (soil types are presented in the section on crop husbandry). The size of the plot was 10 m² (1.25 m x 8 m).

Experimental design. Experiment 1 was laid out in a randomized block design with four blocks, the plots containing 15 variety/mixture treatments. Experiment 2 was in a split-plot design with four blocks, each of the two main plots containing the nitrogen fertilizer treatments were split for the 15 variety/mixture treatments. In both experiments the varieties were mixed mechanically before sowing in all possible combinations (two-, three- and four-variety mixtures) in equal proportions (number of plants per area). Thus, eleven mixtures and four individual varieties were compared.

Varieties. In experiment 1, four high-yielding six-row varieties (Arra, Hja 673, Agneta, Pomo) of contrasting maturity were chosen. The choice of varieties was made in order to harvest all the plots of the experiment at the same time. In experiment 2, the varieties were Ida and Kustaa (two-row), and Agneta and Pomo (six-row) having different morphological characters (for example height, tillering capacity and grain size). The characters of the varieties shown in Table 1 are from long-term field trials (1979—86) carried out by the Agricultural Research Centre in southern Finland (Rantanen and Simojoki 1987).

Crop husbandry. The plots were fertilized at the rate of 500 kg/ha with compound fertilizer NPK (N 2%, P 8%, K 12 %). The amount of nitrogen was adjusted to 80 kg N/ha in experiment 1 and in experiment 2 to 50 and 100 kg N/ha by calcium ammonium nitrate (CAN) (N 27%). The fertilizers were applied between seed-bed preparation and sowing with a fertilizer drill to a depth of 8—12 cm. Seeds were sown at a density of 500 viable seeds/m^2 by machine in rows with 12.5 cm spacing between rows. The crops were kept free of weeds by one application of the herbicide Actril S (2—3 liters/ha mixed with 300 liters of water) containing MCPA (235 g/l), dichlorprop (184 g/l), ioxynil (38 g/l) and bromoxynil (24 g/l) at the time of shoot emergence. The trials (total area of each plot) were harvested by a combine harvester at the time when the latest variety reached its maturity stage (the analysed moisture content was under 30%). The sowing dates, harvesting dates, number of days from sowing to harvesting and soil types were the following:

Exp.	Year	Sowing date	Harvesting date	Number of days	Soil type
1	1983	5 May	4 August	92	Muddy clay
	1984	4 May	9 August	98	Muddy clay
	1985	27 May	26 August	91	Sandy clay
2	1984	22 May	24 August	94	Sandy clay

Sampling and analyses. The number of seedlings was determined before the start of tillering and the number of generative shoots after the complete ear emergence in randomly chosen rows along 3 x 1 m in each plot (or subplot). The density of all the stands corresponded to the amount of viable seeds sown (0.95 to 1.05 times as expected).

Four weeks after sowing in 1983 (exp. 1) samples were taken from three random 1-m-long rows/plot for determination of varietal characters (early growth and development) grown in monocultures. The same amount of plants was removed from mixture stands to avoid grain yield errors. The characters recorded were dry weight per plant, dry weight per main stem, leaf area of the four fully expanded growth leaves of the main shoot and height of the main shoot. The height of the main shoot (pseudostem) was measured from the point where adventitious roots start their growth to the point of the stipule of the latest leaf. Also the developmental stage of the varieties was evaluated by determining the number of tillers and number of fully expanded leaves.

The grain yields were determined (kg/ha at 15% moisture content). From each mixture yield samples of 400 seeds were taken for determination of the seed yield of the components. The separated samples of each mixture as well as samples of each pure stand yield were used for determination of 1000 grain weights (g) in 1983. The grain weight in mixtures was determined by dividing the weight of the fraction by the number of seeds. The grain weight of each monoculture was determined from samples of 3x100 seeds.

Dry weight per plant, leaf area, grain yields and 1000 grain weight were subjected to analyses of variance (randomized block design and split-plot design). Mean separation was accomplished by Tukey's honestly significant difference test (HSD) ($P = 0.05$). The analyses were performed according to Steel and Torrie (1980).

Relative yields (RY) based on grain yields (weight/area) were calculated according to the formula (de WIT and van den Berg 1965) :

$RY = O/M$,

where O is the yield of the variety (species) in mixture and M the yield of the variety (species) in pure stand.

Relative yield total (RYT) was calculated according to the formula (de Wit and van den Berg 1965):

$RYT = RY1 + RY2 \ldots + RYx$,

where RY1, RY2 and ...RYx are the relative yields of variety (species) 1, 2...x respectively.

Competitive ratio (CR) is used as a measure of intercrop (-varietal) competition. The competitive ratio is calculated according to the formula (Willey and Rao 1980)

$CR1 = (RY1/RY2) x (Z2/Z1)$,

where Z1 is the proportion of intercropped

Table 1. General characters of the varieties (RANTANEN and SIMOJOKI 1987).

Variety	Grain yield kg/ha	Growing time days	Height cm	1000-grain weight g	Grain protein content %
Agneta (6-row) (Svalöv 1978)	5100 (= 100)	87	81	37.2	12.0
Arra (6-row) (Jokioinen 1982)	92	83	84	38.1	12.9
Hja 673 (6-row) (Hankkija 1973)	92	83	85	34.0	11.7
Pomo (6-row) (Jokioinen 1969)	90	90	83	37.5	11.9
Ida (2-row) (Weibulsholm 1979)	97	91	70	44.9	12.8
Kustaa (2-row) (Svalöv 1980)	92	93	67	42.9	11.9

area initially allocated to variety (species) 1 and Z2 is the proportion of intercropped area initially allocated to variety (species) 2. Thus the CR term is therefore simply the ratio of the individual RYs of the two component crops, but corrected for the proportions in which the crops were intially sown.

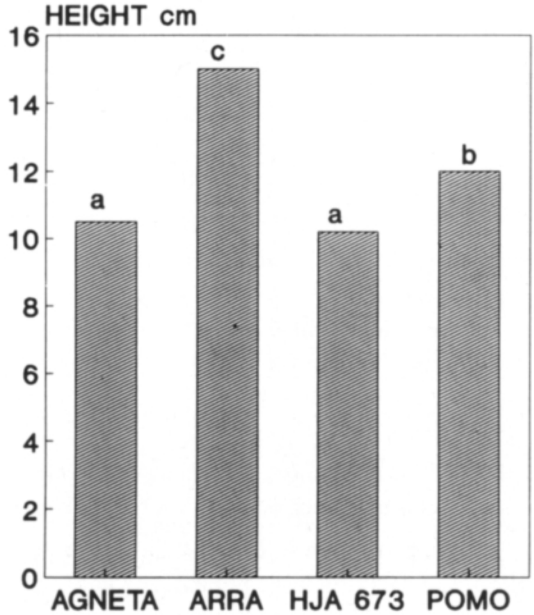

Figure 1. Height of the main stem of different barley cultivars grown in monoculture for four weeks in 1983. Means followed by the same letter are not significantly different at the 5% level (HSD test).

Actual yield (A) is the harvested yield of the mixture. **Expected yield (E)** of the mixture is the average of the yield of the monocultures included in a given mixture.

RESULTS

1. The effect of the variety and growing seasons (Exp. 1)

Vegetative and generative development

Evaluation of the early growth characters of the plants revealed significant differences between the varieties. Arra emerged first, followed by Pomo, Agneta and finally Hja 673. The early variety Arra contained the greatest

Table 2. Phytomass accumulation (dry weight in mg) of different barley cultivars grown in monocultures during the first month of growth in 1983. Dry weight means in the columns followed by the same letter are not significantly different at the 5% level (HSD test).

Cultivar	Phytomass/plant	Phytomass/main shoot
Agneta	193 a	166 ab
Arra	277 b	241 c
Hja 673	186 a	145 a
Pomo	235 ab	183 b

Table 3. Leaf area (LA in mm^2) of different barley cultivars grown in monocultures after the first month of growth in 1983 (N = 120). Leaf area means in the columns followed by the same letter are not significantly different at the 5% level (HSD test).

Cultivar	Position of the leaf on the main shoot				Total LA/main shoot
	1	2	3	4	
Agneta	339 c	427 b	776 b	1305 b	2847 b
Arra	391 d	521 c	752 b	1269 b	2935 b
Hja 673	219 a	309 a	503 a	946 a	1977 a
Pomo	279 b	433 b	819 b	1455 c	2986 b

phytomass (dry weight/plant and dry weight/main shoot) and the other early variety Hja 673 the lowest (Table 2). The main shoot of Arra was the tallest (Fig. 1). The total leaf area and the leaf area of each leaf of Hja 673 was the smallest (Table 3).

The morphological advancement of the varieties varied (Table 4). Over 90% of the main shoots of the earliest varieties, Arra and Hja 673, had the third complete leaf opened. The variety Arra had the lowest number of first order tillers, but the tillers were at the most advanced stage with 89% of the tillers having a fully opened leaf.

In pure stands the change of the growth stage from stem extension to heading started first in the Arra stand, followed by Hja 673, Agneta and finally Pomo. At the end of heading time there were 1.2 times more ($p = 0.09$) generative tillers in the stand of the variety Hja 673 than in other stands (data not given). The ratio of actual number of heads of each mixture to expected number approached one (0.95 to 1.05) by the end of the heading (data not given).

Table 4. The morphological development of different barley cultivars grown in monocultures after the first month of growth in 1983 (N = 120).

Cultivar	Stage of morphological development					
	S1	S2	S3	M3	S11	S21
Agneta	85	11	0	62	55	8
Arra	79	33	0	99	89	3
Hja 673	83	65	3	93	78	19
Pomo	86	51	0	73	71	5

S1 = % of seedlings with the first tiller
S2 = % of seedlings with the second tiller
S3 = % of seedlings with the third tiller
M3 = % of the main shoots with the third fully opened leaf
S11 = % of the first tillers with the first fully opened leaf
S21 = % of the second tillers with the first fully opened leaf

Actual and expected grain yields

The results showed clearly that the overall effect of the number of components in the mixture on the grain yield was poor (Table 5). Two-variety mixtures yielded 0.4% and three-variety mixtures 1.7% more whereas, four-variety mixtures yielded 0.5% less than the mean yield of the varieties grown in pure stands.

The calculated mean yields over the years 1983 to 1985 showed that no statistically significant ($p > 0.05$) differences between the yields of mixtures existed, whereas the yields of monocultures differed from each other ($p < 0.05$) (Table 5). The yield of Pomo varied the most as determined by the coefficient of variation (Table 5). The yield of the mixture of Agneta, Arra and Hja 673 was the most stable.

In general, the yield of a mixture was between the yields of the components grown in pure stand. Overyielding of some mixtures took place, but the difference was not statistically significant.

In every year the actual yields of the mixtures correlated with the expected yields of the mixtures (1983 $r = 0.841^{**}$, 1984 $r = 0.672^{*}$

Table 5. The grain yield (kg/ha) of monocultures and mixtures of barley cultivars in 1983—1985. A/E is of the ratio the actual and expected yield of the mixtures. CV = Coefficient of variation of grain yields (all the yields in groups are included, e.g. in monocultures N = 12 etc.). Grain yield means in year columns, grain yield means in the average column and grain yield means in the average row followed by the same letter are not significantly different at the 5% level (HSD test).

Stand	Year								
	1983		1984		1985		Average		
	Grain yield	A/E	Grain yield	A/E	Grain yield	A/E	Grain yield	A/E	CV
Agneta(Ag)	4752 bc		5613 bc		4508 bcde		4958 b		9.6
Arra (Ar)	4679 abc		5212 ab		4540 bcde		4810 ab		6.0
Hja673 (Hj)	4276 a		5618 bc		4716 de		4870 ab		11.5
Pomo (Po)	4560 abc		5369 abc		3608 a		4512 a		16.0
AgAr	4865 c	103	5299 abc	98	4440 bcde	98	4868 ab	100	7.2
AgHj	4611 abc	102	5691 c	101	4618 bcde	100	4973 b	101	10.2
AgPo	4735 bc	102	5554 bc	101	4349 bcd	107	4879 ab	103	10.3
ArHj	4590 abc	103	5457 abc	101	4430 bcde	95	4825 ab	100	9.4
ArPo	4761 bc	103	5049 a	95	4303 bc	106	4704 ab	101	6.5
HjPo	4369 ab	99	5244 ab	95	4154 b	100	4589 ab	98	10.3
AgArHj	4767 bc	104	5273 ab	96	4787 e	104	4942 b	101	4.7
AgArPo	4796 c	103	5570 bc	103	4274 bc	101	4880 ab	102	10.9
AgHjPo	4692 bc	104	5528 bc	100	4300 bc	101	4840 ab	102	10.6
ArHjPo	4646 abc	103	5598 bc	104	4196 b	98	4813 ab	101	12.1
AgArHjPo	4502 abc	99	5579 bc	102	4206 b	97	4762 ab	99	12.4
Average	4640 a		5453 b		4362 a		4815		
Mono	4567	100	5453	100	4343	100	4788	100	11.7
2-mixture	4655	102	5382	99	4382	101	4806	100	9.5
3-mixture	4725	103	5492	101	4389	101	4869	102	10.0
4-mixture	4502	99	5579	102	4206	97	4762	99	12.4

and 1985 r = 0.703*). Examination of the ratio between the actual and the expected yields of two- and three-variety mixtures revealed that the ratio was more likely to be above one (55% of the two- and 75% of the three-variety mixtures) than under one (33% of the two-and 17% of the three-variety mixtures). The actual yield of the four-variety mixture was lower than expected in two cases out of three.

The relative yields (RY) and the relative yield totals (RYT)

The relative yield of the variety should be 0.50 in two-variety, 0.33 in three-variety and 0.25 in four-variety mixtures if they occupy the same space in the mixture as in the monoculture. The variety Arra was always able to occupy more space in mixtures than in monocultures (Tables 6, 7 and 8). Also the relative yields of Arra varied the least. In general, Hja 673 occupied less space in mixtures than in monocultures. In 1985, however, the relative yields of Hja 673 exceeded the expected in some mixtures. The relative yields of Agneta and Pomo fluctuated above and below the expected value.

In two-variety mixtures the correlation (RYj > RYi) between the increase and decrease of the relative yields of the components was obvious (r = —0.792 ***, df = 16). In three-variety mixtures the correlation (RYj > RYi > RYz) between the increase and the decrease of the relative yields of the components was not clearly explicable (RYj/RYz r = —0.311 ns, RYj/RYi r = —0.322 ns, RYi/RYz r = —0.470 ns).

The relative yield total of a given mixture was close to one (Table 9). The relative yield total of 55% of two-variety mixtures and 67%

Table 6. Relative yields of different barley varieties grown in two-variety mixtures in 1983—1985. CV = coefficient of variation due to the year (y) and the mixtures (m).

		Component in the mixture						
Variety	Year	Ag	Ar	Hj	Po	Average	CV(y)	CV(m)
Agneta	1983		0.37	0.57	0.46	0.47		
(Ag)	1984		0.39	0.58	0.58	0.52		
	1985		0.37	0.45	0.52	0.45		
	Average		0.38	0.53	0.52	0.48	6.1	14.3
Arra	1983	0.67		0.66	0.57	0.63		
(Ar)	1984	0.59		0.67	0.62	0.63		
	1985	0.61		0.58	0.60	0.60		
	Average	0.62		0.64	0.60	0.62	2.3	2.6
Hja 673	1983	0.45	0.36		0.37	0.39		
(Hj)	1984	0.43	0.35		0.46	0.41		
	1985	0.55	0.38		0.52	0.48		
	Average	0.48	0.36		0.45	0.43	9.0	11.9
Pomo	1983	0.55	0.45	0.60		0.53		
(Po)	1984	0.43	0.34	0.49		0.42		
	1985	0.55	0.44	0.47		0.47		
	Average	0.51	0.41	0.52		0.48	9.5	10.3

Table 7. Relative yields of different barley varieties grown in three-variety mixtures in 1983—1985. CV = coefficient of variation due to the years (y) and the mixtures (m).

		Components in the mixture								
		Ar	Ar	Hj	Ag	Ag	Ag			
Variety	Year	Hj	Po	Po	Hj	Po	Ar	Average	CV(y)	CV(m)
Agneta	1983	0.30	0.32	0.34				0.32		
(Ag)	1984	0.32	0.33	0.39				0.35		
	1985	0.30	0.27	0.28				0.28		
	Average	0.31	0.31	0.34				0.32	9.0	4.4
	1983			0.44	0.49	0.41		0.45		
Arra	1984			0.50	0.42	0.47		0.46		
(Ar)	1985			0.41	0.45	0.44		0.43		
	Average			0.45	0.45	0.44		0.45	2.8	1.0
	1983		0.22			0.26	0.25	0.24		
Hja 673	1984		0.28			0.29	0.23	0.27		
(Hj)	1985		0.29			0.39	0.30	0.33		
	Average		0.26			0.31	0.26	0.28	13.4	8.4
	1983	0.35			0.42		0.28	0.35		
Pomo	1984	0.26			0.31		0.26	0.28		
(Po)	1985	0.28			0.32		0.30	0.30		
	Average	0.30			0.35		0.28	0.31	9.5	9.5

Table 8. Relative yields of different barley varieties grown in four-variety mixtures in 1983—85. CV = coefficient of variation due to the years.

Variety	Year			Average	CV
	1983	1984	1985		
Agneta	0.24	0.28	0.16	0.23	21.7
Arra	0.33	0.36	0.34	0.34	3.7
Hja 673	0.17	0.20	0.23	0.20	12.3
Pomo	0.23	0.19	0.23	0.22	8.6

Table 9. The relative yield totals of barley variety mixtures in 1983—1985. (Ag = Agneta, Ar = Arra, Po = Pomo, Hj = Hja 673)

Mixture	Year			Average
	1983	1984	1985	
AgAr	1.04	0.98	0.98	1.00
AgHj	1.02	1.01	1.00	1.01
AgPo	1.01	1.01	1.07	1.03
ArHj	1.02	1.02	0.96	1.00
ArPo	1.02	0.96	1.04	1.01
HjPo	0.97	0.95	0.99	0.97
AgArHj	1.04	0.97	1.05	1.02
AgArPo	1.01	1.06	1.01	1.03
AgHjPo	1.02	0.99	0.99	1.00
ArHjPo	1.01	1.04	0.98	1.01
AgArHjPo	0.97	1.03	0.96	0.99
Average	1.01	1.00	1.00	1.00
2-mixture	1.01	0.99	1.01	1.00
3-mixture	1.02	1.02	1.01	1.02
4-mixture	0.97	1.03	0.96	0.99

of three-variety mixtures was above one. In one case out of three the relative yield total of the four-variety mixture was above one. It is important to note that in the three successive years any individual variety did not consistently contribute positively or negatively to the relative yield totals of all its mixtures.

Competitive ratio (CR)

The results presented in Tables 10, 11 and 12 show clearly that the earliest variety Arra was the most dominant variety (CR > 1). The competitive ratio of Arra was the most stable compared to other varieties (Table 13). The other early variety Hja 673 was in general the subordinate one. However, in 1985 Hja 673 was equal to or more competitive than Agneta or Pomo. The competitive relationship be-

Table 10. Competitive ratio of different barley varieties grown in two-variety mixtures in 1983—1985.

		Component in the mixture				
Variety	Year	Ag	Ar	Hj	Po	Average
Agneta (Ag)	1983		0.55	1.26	0.83	0.88
	1984		0.66	1.35	1.35	1.12
	1985		0.61	0.82	0.95	0.79
	Average		0.61	1.14	1.04	0.93
Arra (Ar)	1983	1.81		1.83	1.26	1.65
	1984	1.51		1.91	1.82	1.75
	1985	1.65		1.53	1.36	1.51
	Average	1.67		1.76	1.48	1.64
Hja 673 (Hj)	1983	0.79	0.55		0.62	0.65
	1984	0.74	0.52		0.94	0.73
	1985	1.22	0.66		1.11	1.00
	Average	0.84	0.58		0.89	0.77
Pomo (Po)	1983	1.20	0.79	1.62		1.20
	1984	0.72	0.55	1.07		0.79
	1985	1.06	0.73	0.90		0.90
	Average	0.99	0.69	1.20		0.96

Table 11. Competitive ratio of different barley varieties grown in three-variety mixtures in 1983—1985.

Variety	Year	Mixture Ag — Ar — Hj			Ag — Ar — Po			Ag — Hj — Po			Ar — Hj — Po			Avg.
		Ag	Ar	Hj	Ag	Ar	Po	Ag	Hj	Po	Ar	Hj	Po	
Agneta	1983		0.61	1.20		0.70	1.14		1.31	0.81				0.96
(Ag)	1984		0.76	1.39		0.70	1.27		1.34	1.26				1.12
	1985		0.67	1.00		0.61	0.90		0.72	0.88				0.80
	Average		0.68	1.20		0.67	1.10		1.12	0.98				0.96
Arra	1983	1.63		1.96	1.28		1.45					2.00	1.26	1.60
(Ar)	1984	1.31		1.83	1.42		1.81					1.79	1.92	1.68
	1985	1.50		1.50	1.67		1.47					1.41	1.46	1.50
	Average	1.48		1.76	1.46		1.58					1.73	1.55	1.59
Hja 673	1983	0.83	0.51					0.76		0.62	0.50		0.63	0.64
(Hj)	1984	0.72	0.55					0.74		0.94	0.56		1.06	0.76
	1985	1.00	0.67					1.39		1.22	0.71		1.04	1.01
	Average	0.85	0.58					0.96		0.93	0.59		0.91	0.80
Pomo	1983				0.88	0.68		1.24	1.62		0.80	1.56		1.13
(Po)	1984				0.79	0.55		0.79	1.07		0.56	1.08		0.81
	1985				1.11	0.68		1.14	0.82		0.68	0.97		0.90
	Average				0.93	0.64		1.06	1.17		0.68	1.20		0.95

tween the latest varieties Pomo and Agneta was rather inconsistent. In general, the rank between the competitive ratio of the varieties in a given year was rather constant irrespective of the number of components in the mixture.

Table 12. Competitive ratio of different barley varieties grown in four-variety mixtures in 1983—1985.

Variety	Year	Mixture Ag	Ar	Hj	Po	Average
Agneta	1983		0.73	1.41	1.03	1.06
(Ag)	1984		0.78	1.40	1.47	1.22
	1985		0.47	0.70	0.69	0.62
	Average		0.66	1.17	1.06	0.97
Arra	1983	1.38		1.94	1.43	1.58
(Ar)	1984	1.29		1.80	1.89	1.66
	1985	2.13		1.48	1.48	1.70
	Average	1.60		1.74	1.60	1.65
Hja 673	1983	0.71	0.52		0.74	0.66
(Hj)	1984	0.71	0.56		1.05	0.77
	1985	1.44	0.68		1.00	1.04
	Average	0.95	0.59		0.93	0.82
Pomo	1983	0.93	0.70	1.35		0.99
(Po)	1984	0.67	0.53	0.95		0.72
	1985	1.38	0.68	1.00		1.02
	Average	0.99	0.64	1.10		0.91

Table 13. The variation of competitive ratio of different barley varieties as determined by coefficient of variation (CV) due to the years (y) and the mixtures (m) in 1983—1985.

Variety	Mixture	CV(y)	CV(m)
Agneta	two-variety	15.0	24.7
	three-variety	13.6	21.9
	four-variety	26.2	22.8
Arra	two-variety	6.0	7.3
	three-variety	4.6	7.2
	four-variety	3.0	4.0
Hja673	two-variety	22.6	17.6
	three-variety	19.3	19.7
	four-variety	19.5	20.2
Pomo	two-variety	18.0	21.8
	three-variety	14.2	23.8
	four-variety	14.8	21.6

Grain weight

The environmental conditions in the mixtures reduced the grain weight of Agneta and Hja 673 compared with their monocultures (data not shown). The grain weight of Arra was usually higher in mixtures than in monoculture. There was no relationship between the grain weight of Pomo whether grown in monoculture or in mixtures.

2. The effect of the variety and the level of nitrogen fertilization (Exp.2)

Actual and expected grain yields

Increasing nitrogen fertilization from 50 kg/ha to 100 kg/ha had a negative effect on the mean yield ($p < 0.05$) (Table 14). The average yield of the monocultures was the lowest. The average yield of the mixtures (two-, three- and four-variety mixtures) increased when the number of components in the stand increased. The yield of mixtures varied less than the yield of monocultures.

Table 14. The grain yield (kg/ha) of monocultures and mixtures of barley cultivars at two levels of nitrogen fertilization. A/E is the ratio of the actual and expected yield of the mixtures. CV = Coefficient of variation of grain yields (all the yields in groups are included). Grain yield means in the average column and grain yield means in the average row followed by the same letter are not significantly different at the 5% level (HSD test).

Stand	Nitrogen fertilization (kg N/ha)						
	50		100		Average		
	Grain yield	A/E	Grain yield	A/E	Grain yield	A/E	CV
Agneta(Ag)	5884		5255		5570 bc		
Ida (Id)	6058		5417		5738 c		
Kustaa (Ku)	6070		5210		5640 bc		
Pomo (Po)	3828		3871		3850 a		
AgId	5801	97	5800	109	5801 c	103	
AgKu	6041	101	6040	115	6041 c	108	
AgPo	5272	109	4842	106	5057 bc	107	
IdKu	5679	94	5410	102	5545 bc	97	
IdPo	5662	115	4878	105	5270 bc	110	
KuPo	4848	98	4451	98	4650 ab	98	
AgIdKu	6167	103	5801	110	5984 c	106	
AgIdPo	5613	107	4967	103	5290 bc	105	
AgKuPo	5044	96	5170	108	5107 bc	102	
IdKuPo	5852	110	4934	102	5393 bc	106	
AgIdKuPo	5832	107	5352	108	5592 bc	108	
Average	5577 a		5160 b		5370		
Mono	5460	100	4938	100	5199	100	16.2
2-mixture	5551	102	5237	106	5394	104	9.4
3-mixture	5669	104	5218	106	5444	105	8.1
4-mixture	5832	107	5352	108	5592	108	4.3

The yield of a given mixture was usually between the monoculture yields of the components. The overyielding which occurred was not statistically significant. The correlation between the actual yields and the expected yields was obvious ($r = 0.802^{***}$, df = 20).

The ratio of the actual to the expected yields of mixtures was more frequently above one (67% n = 12 of the two- and 87% n = 8 of the three-variety mixtures) than below one (33%

Table 15. Relative yields of different barley varieties grown in two-variety mixtures at two levels of nitrogen fertilization. CV = coefficient of variation due to the nitrogen fertilization (n) and the mixtures (m).

Variety	Nitrogen (kg N/ha)	Component in the mixture				Average	CV(m)	CV(n)
		Ag	Id	Ku	Po			
Agneta	50		0.52	0.61	0.57	0.57		
(Ag)	100		0.65	0.67	0.59	0.64		
	Average		0.59	0.64	0.58	0.60	4.4	5.8
Ida	50	0.45		0.47	0.57	0.50		
(Id)	100	0.44		0.54	0.53	0.50		
	Average	0.45		0.51	0.55	0.50	8.2	0.0
Kustaa	50	0.41	0.47		0.50	0.46		
(Ku)	100	0.49	0.48		0.47	0.48		
	Average	0.45	0.48		0.49	0.47	3.6	2.1
Pomo	50	0.50	0.58	0.48		0.52		
(Po)	100	0.45	0.53	0.53		0.50		
	Average	0.48	0.56	0.51		0.52	6.4	1.9

Table 16. Relative yields of different barley varieties grown in three-variety mixtures at two levels of nitrogen fertilization. CV = coefficient of variation due to the nitrogen fertilization (n) and the mixtures (m).

Variety	Nitrogen (kg N/ha)	Components in the mixture						Average	CV(m)	CV(n)
		Id Ku	Id Po	Ku Po	Ag Ku	Ag Po	Ag Id			
Agneta	50	0.43	0.41	0.36				0.40		
(Ag)	100	0.48	0.43	0.45				0.45		
	Average	0.46	0.42	0.41				0.43	8.5	5.8
Ida	50			0.37	0.33	0.30		0.33		
(Id)	100			0.37	0.30	0.29		0.32		
	Average			0.37	0.32	0.30		0.33	8.9	1.5
Kustaa	50		0.36			0.26	0.27	0.30		
(Ku)	100		0.31			0.29	0.32	0.31		
	Average		0.34			0.28	0.30	0.31	8.1	1.6
Pomo	50	0.37			0.35		0.36	0.36		
(Po)	100	0.33			0.34		0.30	0.32		
	Average	0.36			0.35		0.33	0.35	3.6	5.7

Table 17. Relative yields of different barley varieties grown in four-variety mixture at two levels of nitrogen fertilization. CV = coefficient of variation due to the level of nitrogen fertilization.

Variety	Nitrogen fertilization (kg N/ha)			
	50	100	Average	CV
Agneta	0.33	0.35	0.34	2.9
Ida	0.21	0.25	0.23	8.7
Kustaa	0.25	0.23	0.24	4.2
Pomo	0.29	0.25	0.27	7.4

Table 18. The relative yield totals of barley variety mixtures at two levels of nitrogen fertilization (Ag = Agneta, Po = Pomo, Id = Ida, Ku = Kustaa).

Stand	Nitrogen fertilization (kg N/ha)		
	50	100	Average
AgId	0.97	1.09	1.03
AgKu	1.01	1.15	1.08
AgPo	1.07	1.04	1.06
IdKu	0.94	1.02	0.98
IdPo	1.15	1.05	1.10
KuPo	0.98	0.99	0.99
AgIdKu	1.03	1.10	1.07
AgIdPo	1.07	1.02	1.05
AgKuPo	0.97	1.08	1.03
IdKuPo	1.10	1.02	1.06
AgIdKuPo	1.08	1.08	1.08
Average	1.03	1.06	1.04
2-mixture	1.02	1.06	1.04
3-mixture	1.04	1.06	1.05
4-mixture	1.08	1.08	1.08

of the two-and 17% of the three-variety mixtures). It is important to note that the actual yields were usually higher than expected more frequently at low yielding conditions (i.e. at high nitrogen level) than at high yielding conditions (Table 14).

The relative yields (RY) and the relative yield totals (RYT)

The six-row variety Agneta occupied more space in all the mixtures than in monoculture (Tables 15, 16 and 17). Increasing nitrogen fertilization intensified the use of the space by Agneta. The two-row variety Kustaa was usually able to use the space less efficiently in mixtures than in monoculture. The relative yields of the six-row variety Pomo and the two-row variety Ida varied both above and below the expected value.

The reader should observe that at the high nitrogen level almost all the relative yield to-

Table 19. Competitive ratio of different barley varieties grown in two-variety mixtures at two levels of nitrogen fertilization (kgN/ha).

Variety	Nitrogen	Component in the mixture				Average
		Ag	Id	Ku	Po	
Agneta	50		1.15	1.49	1.14	1.26
(Ag)	100		1.49	1.38	1.31	1.39
	Average		1.32	1.44	1.23	1.33
Ida	50	0.87		1.00	0.99	0.95
(Id)	100	0.67		1.14	1.00	0.94
	Average	0.77		1.07	0.96	0.95
Kustaa	50	0.67	1.00		1.02	0.90
(Ku)	100	0.72	0.88		0.89	0.83
	Average	0.70	0.94		0.96	0.87
Pomo	50	0.88	1.01	0.98		0.96
(Po)	100	0.77	1.00	1.13		0.97
	Average	0.83	1.01	1.06		0.97

tals were greater than one (Table 18). At low level of nitrogen fertilization 50% of the two-, 75% of the three-variety mixtures and the four-variety mixture had an advantage over monocultures (RYT > 1).

Competitive ratio (CR)

The six-row variety Agneta was the dominant component in all the mixtures (CR > 1) (Tables 19, 20 and 21). The competitive ratio of Agneta was also the most stable in different mixtures compared to other varieties (Table 22). The dominance of Agneta usually increased as nitrogen fertilization increased. Almost without exception the two-row variety Kustaa was the subordinate variety. The com-

Table 20. Competitive ratio of different barley varieties grown in three-variety mixtures at two levels of nitrogen fertilization (kgN/ha).

Variety		Mixture												
	N	Ag — Id — Ku			Ag — Id — Po			Ag — Ku — Po			Id — Ku — Po			Avg.
Agneta	50		1.28	1.61		1.35	1.13		1.41	1.03				1.30
(Ag)	100		1.59	1.48		1.50	1.44		1.55	1.30				1.48
	Average		1.44	1.55		1.43	1.30		1.48	1.17				1.40
Ida	50	0.78		1.25	0.74		0.84					1.01	0.98	0.93
(Id)	100	0.63		0.93	0.67		0.96					1.20	1.13	0.92
	Average	0.71		1.09	0.71		0.90					1.11	1.06	0.93
Kustaa	50	0.62	0.80					0.71		0.73	0.99		0.97	0.80
(Ku)	100	0.68	1.07					0.65		0.84	0.83		0.94	0.84
	Average	0.65	0.94					0.68		0.79	0.91		0.96	0.82
Pomo	50				0.88	1.20		0.97	1.37		1.02	1.03		1.08
(Po)	100				0.70	1.05		0.77	1.19		0.89	1.06		0.94
	Average				0.79	1.13		0.87	1.28		0.96	1.05		1.01

Table 21. Competitive ratio of different barley varieties grown in four-variety mixtures at two levels of nitrogen fertilization (kgN/ha).

Variety	Nitrogen		Component in the mixture			
		Ag	Id	Ku	Po	Average
Agneta	50		1.55	1.27	1.12	1.31
(Ag)	100		1.41	1.51	1.46	1.46
	Average		1.48	1.39	1.29	1.39
Ida	50	0.64		0.82	0.72	0.72
(Id)	100	0.70		1.06	1.03	0.93
	Average	0.67		0.94	0.88	0.83
Kustaa	50	0.78	1.21		0.87	0.95
(Ku)	100	0.66	0.94		0.96	0.85
	Average	0.72	1.08		0.92	0.90
Pomo	50	0.88	1.38	1.13		1.13
(Po)	100	0.68	0.96	1.03		0.89
	Average	0.78	1.17	1.08		1.01

Table 22. The variation of competitive ratio of different barley varieties as determined by coefficient of variation (CV) due to the mixtures (m) and the nitrogen fertilization (n).

Variety	Mixture	CV(m)	CV(n)
Agneta	two-variety	6.5	4.9
	three-variety	8.9	6.4
	four-variety	5.6	5.4
Ida	two-variety	13.3	0.5
	three-variety	18.2	0.5
	four-variety	13.9	12.7
Kustaa	two-variety	13.6	4.0
	three-variety	15.3	2.4
	four-variety	16.4	5.6
Pomo	two-variety	10.2	0.5
	three-variety	16.1	6.9
	four-variety	16.5	11.9

petitive relationship between the six-row variety Pomo and two-row variety Ida was inconsistent.

DISCUSSION

Occurrence of yield advantage

The comparison between the average yields of mixtures and monocultures in the second experiment of the present study suggests that the increasing number of components in the mixture might increase the yields. This agrees with the results of NITSZCHE and HESSELBACH (1983) who grew six varieties of barley in all possible combinations. However, in the 3-year experiment in the present study the blend responses of 0.4% (two components), 1.7% (three components) and —0.5% (four components) did not support the argument that the yield increase of mixtures depends in general on the number of varieties combined. This agrees with the results of GIEFFERS and HESSELBACH (1988). In addition, CLAY and ALLARD (1969) also found no apparent relation between the number of components and the degree of deviation from expectation.

The present results showed that the yield of the mixture was often equal to the means of the components grown in monoculture but also exceeded them. Occasionally the yield of the mixture even exceeded the highest yielding component grown alone, i.e. the mixture overyielded. However, it should be emphasized that the overyielding was never statistically significant. It was uncommon for a mixture to yield less than the mean of its components. These results agree rather well with the earlier work reviewed by SIMMONDS (1962), TRENBATH (1974) and WOLFE (1985). The present results are also in accordance with recent published studies of barley variety mixtures by BAKER and BRIGGS (1984), HOUMOELLER et al. (1986), KARJALAINEN and HIIVOLA (1987), GIEFFERS and HESSELBACH (1988), IBENTHAL et al. (1988) and AUFHAMMER and STUTZEL (1989).

The results of the first experiment show that the performance of a mixture can be predicted at least reasonably well from the performance of the pure variety components. This rather close positive relationship between pure variety and mixture performance suggests that any complementary or compensatory effects that do occur are of minor importance. The range of individual blend responses observed in the second experiment (—6.7% to 14.5%) may imply certain complementary and competitional effects but may also be partly due to the large random variation, which occurred in the experiment (differences over 1072 kg/ha between the yields of the stands having different compositional structure were significant at the level of 5%).

In addition to the comparison of the actual and expected yields of the mixtures, the de Wit model (RYT-value) was used to evaluate the productivity of mixtures. The six varieties used in the present experiments were selected in respect to contrasting agronomic types differing in yield structures, morphological characters and growing time. The mixtures were also grown under varying environmental conditions. The results of these experiments in most cases are well compatible with the de Wit competition model agreeing with the results of earlier barley varietal experiments (e.g. SANDFAER 1970, BLIJENBURG and SNEEP 1975). Thus, the results suggest that competition solely for the same space is rather common in mixtures of barley varieties and the yield advantage is marginal.

It should be emphasized that the RYT-values of the mixtures of Agneta and Pomo in both experiments exceeded one. Also the RYT-values of several other mixtures in the second experiment exceeded one. This suggests that some varieties might partly occupy different spaces in certain conditions. Results from the experiments by ALLARD and ADAMS (1969) calculated by SANDFAER (1970) also indicated that some genotypes of barley may partly occupy different spaces.

Reasons for yield advantage

When deviations of RYT-values from unity occur, as at the high level of nitrogen fertilization in the present trial, some form of complementary use of resources (annidation) may be suspected (TRENBATH 1974). The mechanisms resulting in the RYT-value being greater than one have been shown to be various (TRENBATH 1974), but the data collected from the present experiments is limited in this respect.

Theoretically, a mixture of varieties may benefit from the association by production of a more uniform leaf distribution or by reduction of competition among integrated root systems resulting in either temporal or spatial differences of use of growth factors. The evidence from the experiments of PALVAKUL et al. (1973) and LANG et al. (1975) suggests that such effects are likely to be small, or they do not favour mixing provided disease buffering is not an important factor. However, AUFHAMMER and STUTZEL (1989) reported that the yield advantage of barley mixtures could not be explained by the observed levels of disease or lodging. This suggests that also other mechanisms may operate.

Competitive ability and consequences of competition

In addition to the growing season and the level of nitrogen fertilization, neighbours in the mixture were also found to influence the competitive ability of the varieties. For example, the competitive relationship between Pomo and Hja 673 varied from year to year. Increasing nitrogen fertilization also increased the dominance of a strong aggressor, Agneta. Thus competitive ability was a relative character of a variety. In other experiments the competitive ability of barley varieties varied also due to the environment (SANDFAER 1970). These results also showed that the use of resources in mixtures is not at equilibrium in different environments.

No consistent relationship was observed between competitive ability and yield ability in pure stands of different varieties. This agrees with the results of SANDFAER (1970) and SPITTERS (1979). The results of the present study, where the competitive abilities of two- and six-row barleys were compared, suggest that an erect type combined with greater height, as in the case of Agneta, may be more favourable. However, the competitive relationship between the six-row variety Pomo (taller, erect) and the two-row variety Ida (shorter, prostate) was unpredictable. Thus caution should be exercised in view of previous unsuccessful attempts (SAKAI 1961, VALENTINE 1982) to relate competitive ability only to an individual plant character.

The data collected in 1983 suggests that the superior competitive ability of Arra in all circumstances might be related to the early germination. Also the growth habit of Arra might favour its success in mixtures. The characters of Hja 673 during the early stages of growth were unfavourable in the course of competition in 1983. The results of the competitive ability of the varieties in respect to the early growth agree rather well with the results of BLIJENBURG and SNEEP (1975) and with the model constructed by SPITTERS and van den BERG (1982) and SPITTERS (1984). SPITTERS and van den Berg (1982) concluded that the competitive ability of a plant is determined by the space it is able to occupy at the beginning of the growing season and the relative rate at which a single plant is able to expand the space it has already occupied. The varieties which were taller and had a larger leaf area during the early stages of development might shade the shorter plants, decreasing their root/shoot ratio (see Briggs 1978 p.274). The plants of the better competitor might have more light available in mixtures than in monocultures, thus increasing their root/shoot ratio.

When the competitive relationship between two genotypes as in the case of Agneta and Pomo, was rather inconsistent even the vigour of seed or the grain weight might determine the competitiveness of a genotype. This is because both characteristics of a seed were shown (Kangasmäki pers.com.) to affect the growth rate of seedlings.

In the present trial, some yield reductions and yield increases of the components grown in mixtures may partly be explained by the results of grain weight. Both Spitters (1979) and Valentine (1982) observed that competition between barley varieties affected more strongly the number of ears/plant and the number of grains/ear than the grain weight.

Limitation of replacement series design

The fact that the competitive ability of the six barley varieties differed in many cases from each other shows that there occurred also intergenotypic competition in mixtures. However, the limitation of the indices like CR and RY based on the replacement design is their inability to separate intra- and intergenotypic competition quantitatively from each other. Thus the results from replacement series can give only qualitative insight into the relative magnitudes of the effects of intra-and intergenotypic competition (Firbank and Watkinson 1985, 1990, Håkansson 1988).

The results of the experiments based on the de Wit model can be also biased, because only one density was used (Connolly 1986). In the present experiments the indices were based on the yields per unit area of the varieties, which typically change less rapidly as the monoculture density changes than does the yield per plant. According to Harper (1977 p. 152—4) the total plant yield is rather independent of density except when plants are very small or widely spaced (the law of constant final yield). The selected density used in these experiments was very likely near optimum in respect to achieve constant final yield of barley in northern growing conditions (see e.g. Erviö 1983).

Stability of mixtures

A frequently claimed advantage of mixtures is their capability to deal with environmental variability, implicitly equivalent to the avoidance of risk (Vandeermeer 1989). A number of authors reviewed by Trenbath (1974) and by Wolfe (1985) have noted the improved stability of mixtures compared with their components, but also the opposite effect has been noted.

The results of the first experiment indicate that over years only few mixtures were more stable than their most stable component in monoculture; the remaining mixtures showed stabilities between those of their component monoculture. In the second experiment the high level of nitrogen fertilization induced stress in most of the monoculture stands, decreasing the yield whereas some mixtures were insensitive to nitrogen fertilization. This suggests that a mixture may adjust its genotypic or phenotypic state in response to transient fluctuations in environment in such ways that it gives high and stable return. The advantage of mixtures in respect to stability may be partly due to the beneficial effects of compensation. Thus some mixed stands may exhibit populational buffering arising in interactions among different coexisting genotypes and show low »genotype»-environment interaction. This suggests that mixtures might be universal instead of specialized producers according to the terminology introduced by Allard and Bradshaw (1964).

The greatest difficulty in discussing stability is the lack of any clear definition of an index of stability of yield (SCHUTZ and BRIM 1971). The standard measurement of yield variability or yield stability is the coeffiecient of variation which was also used here. One common method of measuring stability of genotypes is to regress the yield of a particular genotype to the mean yield of a group of genotypes over wide range of environments (see EBERHART and RUSSELL 1966). This approach has, however, been criticized, because dependency between genotypic means and environmental means invalidates the analysis of variance of regression (ZHANG and GENG 1986). This is rather obvious in mixture experiments where the independent variable in the regression is the average of a few yields.

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SELOSTUS

Ohralajikkeiden välinen kilpailu ja lajikeseosten sato

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Kahdessa korvaussarjaan perustuvassa kenttäkokeessa tutkittiin ohralajikkeiden välistä kilpailua ja seosten sadontuottoa seosten koostuessa kahden, kolmen ja neljän lajikkeen yhdistelmistä. Ensimmäisessä kokeessa, joka toistettiin kolmena peräkkäisenä vuonna (1983—85), lajikkeet olivat monitahoiset Agneta, Arra, Hja-673 ja Pomo. Toisessa kokeessa (1984), jossa käytettiin myös kahta typpilannoituksen määrää (50 ja 100 kgN/ha), lajikkeet olivat monitahoiset Agneta ja Pomo ja kaksitahoiset Ida, Kustaa.

Lajikkeen valtauskyky ei yleensä ollut genotyypin stabiili ominaisuus lajikkeiden keskinäisten valtaussuhteiden muuttuessa ympäristöstä toiseen (kasvukausi, typpilannoitus). Lajikkeen valtauskyky ei riippunut lajikkeen aikaisuudesta, morfologisista ominaisuuksista (kaksi- ja monitahoiset) eikä puhdaskasvustosadon määrästä. Lajikkeen valtauskykyä edisti nopea alkukehitys Arran ollessa valtaavin lajike.

Ensimmäisen kokeen yhdenkään seoksen kolmen vuoden keskimääräinen jyväsato ei poikennut tilastollisesti merkitsevästi seoksen komponentin puhdaskasvuston jyväsadosta. Toisessa kokeessa joidenkin seosten jyväsato oli tilastollisesti merkitsevästi suurempi kuin seoksen komponenteista vähiten tuottaneen puhdaskasvustosato. Vaikka useiden seosten toteutuneen ja odotetun sadon välinen suhde ja seoksen suhteellinen kokonaissato oli hiukan suurempi kuin yksi, oli seosten satoetu marginaalinen. Yksiselitteisesti seokset eivät olleet vakaampia sadontuottajia kuin puhdaskasvustot vaihtelukertoimella mitattuna. Joidenkin seosten jyväsato kuitenkin vaihteli vähemmän kuin vähiten vaihtelevan komponentin puhdaskasvuston jyväsato.