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The effect of site on competition and yield advantages of mixtures of barley and oats

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Abstract. Competition between six-row barley cv. Agneta and oats cv. Veli, and yield advantages of the mixtures were evaluated in a replacement series field experiment. The experiment was situated in a sloping area.

Although barley was lower yielding (grain yield) than oats when the components were grown in monoculture, barley was dominant in all mixtures irrespective of the site. The competitive ability of barley decreased from the less productive site (top) to the more productive site (bottom). The improved competitive ability of oats was likely due to the faster early growth of oats.

The grain yield of the mixture was about 4% ($p > 0.05$) greater than the yield of the highest yielding component (oats) grown in monoculture on the more productive sites. The grain yield of the mixture was greater than the average yield of the pure stands and also the relative yield total exceeded one irrespective of the site.

The grain weight of the species was independent of the genotypic structure of the stands. The protein content of oats was the highest, being greater in mixtures than in monocultures. The protein yield and the protein content of the mixture was between the values for pure stands.

Index words: Competition, yield, barley, oats, mixtures

INTRODUCTION

In recent years there has been increasing interest in the use of mixtures in practical cultivation. Approximately 50 % of the barley and oat grain produced in Ontario is from mixtures of the two species (300000 ha) (Fejer et al. 1982). Some possible advantages of mixtures are greater yield , greater stability in yield over different environments and lower incidence of disease. The results of earlier studies of barley-oats mixtures have been discussed recently by Jokinen (1991 a,b). In general, mixtures have slightly higher yields than the mean of their components, and even overyielding may occur. The results of some studies also suggest that the relative yield total (RYT) may be greater than one, suggesting that a larger area of land is needed to produce the same yield of each species with monocultures than with a mixture.

Although the competition between plants and the yield advantage of mixtures are different aspects of mixture research, competition has an profound effect on the yield advantage of mixtures. Because plants are competing for limiting environmental resources, the environmental variability may be expected to affect the relationship between plants. According to the resource competition theory developed by TILMAN (1982) the differences in the availability of two resources such as nitrogen and light may have significant effects on the competitive relationship between plants. Thus plants growing in small experimental plots on uniform sites may be too limited to demonstrate the advantages of the versatility of mixtures.

The aim of the present experiment was to evaluate the competition between barley and oats and the yield advantage of the mixture on a sloping area.

MATERIALS AND METHODS

The field experiment was carried out in 1985 on the Kotkaniemi Experimental Farm of Kemira Oy in southern Finland (60° 22′N, 24° 22′E). Six-row Agneta barley and Veli oats were seeded separately (500 seeds/m²) and in an equal mechanical mixture (250/250) (replacement series). The general characters of the cultivars are described elsewhere (JOKINEN 1991b).

A sloping area with three sites (top, middle and bottom) was employed. The soil was finer fine sand with pH 5.7. A split-plot design (sites in main plots and genotypic composition of stand in subplots) was used with four blocks. The plot size was 30 m² (3 m x 10 m) with rows spaced 12.5 cm apart. The rows of subplots were laid along the slope with the subplots of each site being adjacent. The fertilizer was granular NPK (N 16%, P 7%, K 13%), the amount was adjusted to 80 kgN/ha, and the placement method was applied. The sowing date was 17 May. 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 number of plants in each plot was determined by counting the number of seedlings in four randomly selected 1-m-long rows/plot about three weeks after sowing and before the initiation of tillering. At maturity the entire area of each plot was harvested (28 August) and the grain yields were determined (kg/ha at 15% moisture content). From each mixture yield a 50 g sample was taken for determination of the seed yield of the barley and oats components. The separated samples of each mixture as well as samples of each pure stand yield were used for determination of the protein content (%) of the grain by the Kjeldahl method (500 mg with two subsamples) and 1000-grain weights (g) (3 x 100 seeds/sample).

Relative yield (RY) and relative yield total (RYT) were calculated according to the methods of de WIT and van den BERG (1965). Also relative protein yield and relative protein yield total were determined. Competitive ratio (CR) was determined according to the method of WILEY and RAO (1980). The mean yield/area of four replications was calculated before computing the indices.

The grain yields, 1000 grain weights, the protein content of grain and the protein yields were subjected to analyses of variance for split-plot design (STEEL and TORRIE 1980). Mean separation was accomplished by Tukey's honestly significant difference test (HSD) (P = 0.05) (STEEL and TORRIE 1980).

RESULTS AND DISCUSSION

Early development of the plants

Barley seed sown at the top of the hill emerged first, a few days earlier than oats. In the middle of the slope and especially at the bottom there were no differences in the time

Table 1. The grain yields, relative grain yields (RY), relative grain yield totals (RYT), actual grain yield/expected grain yield (A/E) and competitive ratio of barley to oats (CR) at different sites. BB = barley yield in pure stand, OO = oats yield in pure stand, M = mixture yield, BM = barley yield in mixture, OM = oats yield in mixture, RYB = barley relative yield, RYO = oats relative yield. Grain yield means within site rows, 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).

	Grain yield (kg/ha)						Relative values				
Site	BB	OO	M	Average	BM	OM	RYB	RYO	RYT	A/E	CR
Top	5039a	5907b	5674b	5540a	3601	2073	0.71	0.35	1.06	1.04	2.03
Middle	5473a	6083b	6349b	5969b	4181	2169	0.76	0.36	1.12	1.10	2.11
Bottom	6161a	6319a	6584a	6355c	3813	2772	0.63	0.44	1.07	1.06	1.41
Average	5558a	6103b	6202b	5954	3865	2338	0.70	0.38	1.08	1.07	1.85

of emergence between the two species. This might be due to the greatest moisture of the soil being at the bottom of the slope according to observations.

At the beginning of the growing season the density was approximately the same (0.95—1.05) as expected (data not given).

The first leaves of barley were longer and wider than those of oats according to observations. This indicates a larger area of photosynthesis during the early stages of growth and development. In other studies, where quantitative measurements have been done, barley was able to build larger phytomass during the initial growth (SYME and BREMNER 1968, TAYLOR 1978, JOKINEN 1991 a) and a greater leaf area (SYME and BREMNER 1968) than oats.

Table 2. The effect of site and genotypic composition on the thousand grain weight (g) of barley and oats. The difference between treatments analysed statistically for each species. BB = barley in pure stand, OO = oats in pure stand, BM = barley in mixture, OM = oats in mixture. Means in the average column and means in the average row, followed by the same letter are not significantly different at the 5% level (HSD test).

	Site			
Species	Top	Middle	Bottom	Average
Barley				
BB	36.8	38.0	37.4	37.4 a
BM	35.5	37.0	37.1	36.5 a
Average	36.2 a	37.5 a	37.3 a	37.0
Oats				
OO	34.0	35.1	35.1	34.7 a
OM	32.8	34.4	35.0	34.0 a
Average	33.4 a	34.8 b	35.1 b	34.4

Competitive ability and grain yield advantage

The reader should observe that barley was more productive in mixtures, both in terms of absolute and relative yields, and was also more competitive than oats as determined by competitive ratio irrespective of the site (Table 1). Thus the magnitude of the monoculture yield was less important in determining the dominance of the component in mixtures, as shown also in other studies (SPITTERS 1979, ALEXANDER et al. 1986, JOKINEN 1991 b).

There were no significant differences in grain weight whether the species were grown alone or in mixtures (Table 2). In other studies of barley-oats mixtures (SYME and BREMNER 1968, JOKINEN 1991 b) it was shown that the number of ears per plant and the number of grains per ear varied more than grain weight in circumstances where differences in monoculture and mixture yields were observed. This suggests that the species competed for the resources, and the dominant-suppression relationship was determinend at earlier stages than during grain filling.

The environment was the least favourable at the top ($p < 0.05$) and the most favourable at the bottom of the hill for grain production ($p < 0.05$) (Table 1). This is an indication of gradual increase and thus improved availability of soil resources through the environmental gradient.

In addition to the main effects there was also interaction between the site and the stand ($p < 0.05$). Barley grown in monoculture was less productive on the top and in the middle of the slope compared with other stands. The mixture overyielded in the middle and at the bottom of the slope. However, the difference between the yield of the mixture and the yield of the oats grown in monoculture (about 4%) was not statistically significant.

Irrespective of the site, both relative yield totals and the ratio of actual and expected yields were greater than one and thus fulfilled the requirements of using a mixture even under variable field conditions (Table 1). Thus from a practical point of view, it might be more advantageous to cultivate these varieties in mixtures than in monoculture.

Both competitive relationship between components and the monoculture yields affected the total grain yield of the mixture (Table 1). When the environment was considerably less favourable for the aggressor grown alone than for the subordinate grown alone, the aggressor being the least productive component grown in monoculture, the mixture did not overyield. Thus the later the growing season as environmental stresses such as decreased availability of nutrients and water or some pathogens reduce the yield of the aggressor, the poorer are the possibilities for the subordinate to compensate. This concerns especially the cases where the share of the space occurs during the very early stages of the growth. In several mixtures of barley and oats a rather severe disease caused by *Rhyncosporium secalis* had only a slight effect on the competitive relationship, the grain yield of the mixture depending more on the yield level of barley grown in monoculture (Karjalainen and Jokinen unpubl.). Also Alexander et al. (1986) found that the relative competitive abilities of wheat cultivars were not reversed when disease was present, the susceptible cultivar being a stronger competitor and yielding less than the resistant cultivar in monoculture.

Competition for resources

The monoculture grain yield of barley increased more than that of oats when the production conditions were improved (Table 1), agreeing with the previous results of Jokinen (1991 a, b) and Vermeulen (1991). In the present experiment, the grain yield of oats, when grown alone, was greater than that of barley in low productivity conditions, which was also observed by Vermeulen (1991) and Jokinen in 1983 (1991 a). Thus these results suggest that barley responds more to soil resources, and oats is better adapted to a low level of soil resources. The earlier emergence of oats at the bottom than at the top had a positive impact on the competitiveness of oats (Table 1). This might be due to the increased availability of light and subsequent faster growth of oats at the bottom. Thus combined with earlier studies of barley cv. Agneta and oats cv. Veli in 1983 (Jokinen 1991 a) the present results suggest that barley cv. Agneta is a superior competitor for light and oats cv. Veli a superior competitor for soil resources. This suggestion is based on the resource competition theory (Tilman 1982) which predicts that the species which is the superior competitor for a resource will become less dominant as that resource is added. It will become increasingly dominant as the resource for which it is inferior competitor is added. Thus, it is important to note that in the mixtures of the present trial the increase of light for oats had a stronger influence on the competitive relationship than the influence of the increased soil resources on barley. The competition theory also suggests that each species should be a superior competitor for a particular point along the nutrient:light gradient. Changes in relative availability of these resources should lead to changes in the composition of the community, as occurred earlier (Jokinen 1991 a) as well as in the present experiment (Table 1).

These results show the complexity of competition for resources even in slightly different environments. They also show how the addition of soil resources might increase the yield per se but might also unpredictably modify the competitive relationship between two species because of an interaction between different growth factors.

The species approached a stable coexistence from top to the bottom but did not achieve it, barley still being in all cases a winner. However, these two genotypes can stably coexist in an agricultural environment at a particular point along the productivity gradient (Jokinen 1991 a). According to Vandermeer (1989 p.69), if two species coexist, it is likely that they do so because their niches do not overlap sufficiently. Also the results of relative yield totals (RYT > 1) in the present trial (Table 1) suggests that there might occur resource partitioning between components as shown earlier by Jokinen (1991 a,b).

Additional experiments are, however, needed to confirm that these barley and oats varieties do exhibit the suggested tradeoffs. In the next experiments precise measurements like the phytomass accumulation and availability of growth factors in the course of competition along the productivity gradient should also be done. The reciprocal model should be preferred to the de Wit model (see for example Jokinen 1991 a).

Protein content and protein yield

The protein content of grain yield of oats grown in mixture was the highest ($p<0.05$), whereas the lowest protein content ($p<0.05$) occurred in the grains of barley grown in mixture (Table 3). In low light environments, plants such as oats in the present mixtures might accumulate high nutrient concentrations, but have low carbohydrate contents (Bloom et al. 1985). Along the gradient the protein content decreased, showing a negative correlation between the grain yield and pro-

Table 3. The effect of site and genotypic composition on the protein content (%) of the grain yields. BB = barley in pure stand, OO = oats in pure stand, BM = barley in mixture, OM = oats in mixture, M = mixture. Means in the average column and in the average row followed by the same letter are not significantly different at the 5% level (HSD test).

Site	BB	OO	M	Average	BM	OM
Top	12.8	13.0	12.3	12.7 a	11.2	14.5
Middle	11.2	13.3	11.8	12.1 a	10.7	14.2
Bottom	11.2	13.2	11.8	12.1 a	10.4	13.8
Average	11.7	13.2	12.0	12.3	10.8	14.2
Pure/mixture	a	b	a			
Components	b	c			a	d

Table 4. Protein yields (kg/ha), relative protein yields (RY), relative protein yield totals (RYT) and actual protein yield/expected protein yield (A/E) at different sites. For abbreviations see Table 1. Means in the average column and means in the average row followed by the same letter are not significantly different at the 5% level (HSD test).

	Protein yield (kg/ha)						Relative values			
Site	BB	OO	M	Average	BM	OM	RYB	RYO	RYT	A/E
Top	642	766	698	702 a	402	296	0.63	0.39	1.02	0.99
Middle	614	810	750	725 ab	448	302	0.73	0.37	1.10	1.05
Bottom	687	836	777	767 b	396	382	0.57	0.46	1.02	1.02
Average	647a	804c	741b	731	415	327	0.64	0.41	1.05	1.02

tein content common in cereals.

The protein content of the mixture was lower ($p < 0.05$) than that of oats and about the same as that of barley. Because the dominant component had a lower protein content than the subordinate and the dominant grown in monoculture was lower yielding, the mixture did not overyield in respect to protein yield (Table 4).

The ratio of the actual and expected protein yield of the mixture was close to one. However, the results of relative yield totals of protein yields indicated that the use of mixture might be more advantageous than monocultures with the magnitude of the advantage depending on the environment (Table 4). This agrees to a certain extent with the previous results (Jokinen 1991 b).

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SELOSTUS

Kasvupaikan vaikutus ohran ja kauran väliseen kilpailuun seoskasvustossa ja seoksen satoetuun

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Työssä tutkittiin monitahoisen Agneta-ohran ja Veli-kauran kilpailusuhteita ja seoksen sadontuottoa kenttäkokeessa, jossa koemalli oli korvaussarja. Kenttäkoe sijaitsi viettävällä peltolohkolla.

Vaikka ohran puhdaskasvuston jyväsato oli pienempi kuin kauran, oli ohra dominoiva kaikissa seoksissa kasvupaikasta riippumatta. Seoksen jyväsato ei poikennut tilastollisesti merkitsevästi runsastuottoisimman komponentin (kaura) puhdaskasvuston jyväsadosta. Seoksen jyväsato oli kuitenkin suurempi kuin komponenttien keskimääräinen puhdaskasvustosato seoksen suhteellisen kokonaissadon (RYT) ollessa myös suurempi kuin yksi riippumatta kasvupaikasta. Lajien jyväsadon jyvänpaino oli riippumaton kasvuston genotyyppisestä koostumuksesta. Kauran jyväsadon valkuaispitoisuus oli korkein ollen suurempi seoksessa kuin puhdaskasvustossa. Kauran puhdaskasvuston valkuaissato oli suurin. Seoksen valkuaissato oli jokseenkin yhtä suuri tai suurempi kuin komponenttien keskimääräinen valkuaissato seoksen suhteellisen kokonaisvalkuaissadon ollessa suurempi kuin yksi.