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Mixture of cultivars: pilot field trial of an ecological alternative to improve production or quality of wheat (*Triticum aestivum*)

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Summary

1. Mixtures of wheat cultivars were tested as an ecological alternative to pure culture, for producing either a higher grain yield and/or a better grain quality (higher protein content). Two cultivars of bread wheat (*Triticum aestivum*) were selected: Buck Pucará (BP) a modern high yielding cultivar, and Buck Cencerro (BC), an old low yielding cultivar, but with higher grain protein content. They were grown in the field in a replacement series at two nitrogen levels and at a fixed density of 300 viable seeds m^{-2} for 5 different combinations (mixtures).

2. Nitrogen application influenced total aerial biomass production, number of ears m^{-2} and grain yield, but not the harvest index.

3. Total aerial biomass production after ripening was similar in both cultivars, but BP had a greater grain yield.

4. The mixture of 67% BP and 33% BC produced significantly more total aerial biomass than pure stands of either of the component cultivars.

5. It also produced a grain yield similar to the best yielding cultivar (BP), with an improved grain quality (grain protein content) when no N fertilizer was applied.

6. The mixtures showed a lower harvest index with a higher proportion of resources allocated to competitive structures (stems and leaves). Because of their lower harvest index none of the mixtures had a grain yield greater than that of BP.

7. Without fertilizer the percentage of grain protein of all mixtures was higher than that of BP and similar to BC under pure stands. With nitrogen fertilization, all mixtures showed a similar grain protein content.

8. The results of this study suggests that the use of mixtures of contrasting cultivars could be an ecological alternative to optimize crop production in a low input agriculture.

Key-words: agroecology, biomass production, grain protein content, low input agriculture, nitrogen fertilization.

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Introduction

The increase of grain yield together with grain protein content is an important goal in wheat production. However, this is not easy to achieve because of the inverse relationship that exists between grain yield and grain protein content (Kramer 1979; Löffler, Rauch & Busch 1985). Higher grain yield has been achieved through new cultivars with a greater efficiency in dry matter partition (harvest index) without an increase in total biological productivity (Austin *et al.* 1980; Scholz 1984; Perry & D'Antuono 1989; Slafer & Andrade 1989). However, this achievement has been associated with a decrease in grain protein content (Austin *et al.* 1977; Kramer 1979; Paccaud, Fossati & Hong Shen Cao 1985). Since the nitrogen requirements of high yielding cultivars under low-N conditions cannot adequately be supplied by the remobilization of N stored in the vegetative structures (Sarandón & Gianibelli, 1992) the grain protein content of these cultivars may be severely affected. Nitrogen fertilizers serve to increase both grain yield and grain protein content. However, their higher costs and associated negative environmental impacts (Newbould 1989) are reasons to look for alternative methods of crop production in the context of sustainable agriculture (Geng, Hess & Auburn 1990).

Intercropping is an ecologically appropriate tool for reducing external inputs (Amador & Gliessman 1990). Mixtures of cultivars, selected for their ecological combining ability (i.e. showing a good performance when growing together), have been considered to provide a potential way of increasing crop yield (Harper 1964). Nevertheless, studies on mixture of genotypes of the same species have focused on the competitive ability of mixture components (Harlan & Martini 1938; Jennings & Aquino 1968; Jennings & De Jesus 1968; McKenzie & Grant 1980), or on the behaviour of the mixture in the presence of pathogens (Borlaug 1959; McKenzie & Grant 1980; Knott & Mundt 1990), but not on the productivity of the mixture itself. Recent studies on groundnut (*Arachis hypogaea*) (Rattunde *et al.* 1988) and barley (*Hordeum vulgare*) (Stützel & Aufhammer 1990) have tested mixtures as a means of exploiting morpho-developmental differences among cultivars to increase crop productivity, but they have shown variable results.

Wheat (*Triticum aestivum*) cultivars may differ in their morphology, canopy architecture and physiological attributes as widely as different species do. These differences could result (in some cases) in varying ability to utilize present resources (de Wit 1960; Trenbath 1974). Consequently, the total resource utilization by a mixture of different genotypes may be higher than that by a pure cultivar growing alone. This should lead to a higher biomass production of the mixture, and could eventually result in an increase in grain yield and/or an enhanced grain protein content. Although this is an important measure of quality in wheat, only few studies have considered the effect of mixtures of wheat genotypes on protein content. The objective of this study was to test whether a mixture of two different wheat cultivars could be an alternative to conventional methods for improving grain yield and quality.

Materials and methods

The study was carried out in La Plata, Province of Buenos Aires, Argentina (35°S, 58°W), in a typical argiudoll (an argillic prairie brunizem) soil with the following attributes at sowing: phosphorus: 5·2 ppm; total nitrogen: 0·245%; organic matter: 3·9% and nitrates: 17 ppm. Weather conditions in the location are characterized by a mild climate without dry seasons and mean temperatures of 9°C during winter and 22°C during summer. Annual rainfall is about 970 mm.

Two commercial cultivars of bread wheat (*Triticum aestivum* L.) were selected to match the following conditions: (1) to have different phenotypic characteristics; (2) to have a different grain yield potential and grain protein content; (3) to have a similar crop cycle; (4) to have a similar plant height to reduce shade and allow mechanical harvesting and (5) to be easily identifiable in the mixture at maturity (harvest). One cultivar was Buck Cencerro (BC), a traditional cultivar with a low harvest index, high average tiller weight, moderate tillering capacity, high grain protein content and red coloured ears at maturity. The other cultivar was Buck Pucará (BP), a modern potentially high-yielding cultivar with high harvest index, low average tiller weight, high tillering capacity, high response to N fertilization, low level of grain protein content and white coloured ears at maturity.

The experiment was designed as a replacement series (de Wit 1960) with a constant sowing density of 300 viable seed per m^2, which is the recommended density for these cultivars at the relevant sowing date (July 7). The sowing rate of the two cultivars took into account differences in grain weight and germination rate, so as to achieve the desired proportions. The proportion of each cultivar in each 'mixture' was: (I) 100:0; (II) 67:33; (III) 50:50; (IV) 33:67 and (V) 0:100 of BP and BC, respectively. The seeds of both cultivars were carefully mixed, according to the desired proportion, before sowing.

The various mixtures were sown using a seven-row cone seeder in a randomized block design with four replicates, with a total of 40 plots (5 mixtures × 2 N levels × 4 replicates). Each plot consisted of seven rows 0·20 m apart and 5·50 m long. Within each row there were seeds of both cultivars mixed in the corresponding proportion. Nitrogen fertilizer (90 kg N ha^{-1}) was applied to half of the experiment (20 plots randomly selected) as urea (N-P-K content coded 46–0–0), in three applications each of 30 Kg N ha^{-1} at sowing, at the end of tillering (first detectable node), and at heading (growth stage E59 of Tottman, Makepeace & Broad 1979). All plots received 46 kg ha^{-1} of P_2O_5 as a triple superphosphate (0–46–0) at sowing. The experiment was kept weed-free by herbicide applications. No disease symptoms were observed during the crop cycle, either in pure stands or in mixtures. Weather conditions during the experiment were normal for this location.

At maturity (December 10) three internal rows each 0·50 m long were harvested in each plot and total aerial biomass, number of ears per m^2, grain number per m^2, grain weight and grain yield of each individual cultivar (identified by its ear colour), and of the mixture, were recorded. Grain protein content was determined by the micro-Kjeldahl method (AACC 1983), multiplying the N assay by a factor of 5·7. Relative yield (R) of biomass production, grain yield, grain number and ear number for each cultivar in each mixture and under both fertility conditions

Table 1. Analysis of variance for the effects of nitrogen availability and cultivar mixture (as main sources of variation) and of their interaction on different measures of crop performance: *F* values and associated levels of significance

Variable df (total = 39)	Nitrogen $n = 1$	Mixture $n = 4$	Interaction $n = 4$
Biomass production	103·2***	2·8*	0·85 ns
Grain yield	49·36***	4·05**	0·88 ns
Grains per unit area	60·26***	4·05*	1·12 ns
Ears per unit area	11·65***	4·08***	0·46 ns
Average weight per tiller	7·91**	2·84*	0·12 ns
Grain protein percentage	219·32***	1·09 ns	4·34**
Grain protein per unit area	114·00***	2·37 ns	1·85 ns
Harvest index	0·27 ns	5·69***	0·08 ns

ns: non-significant; * $P <= 0{\cdot}05$; ** $P <= 0{\cdot}01$; *** $P <= 0{\cdot}001$.

was calculated as: $R_{ij} = Y_{ij}/Y_{ii}$, where Y_{ij} is the relative yield of cultivar *i* in mixture with cultivar *j*, and Y_{ii} is the yield of the cultivar *i* when growing in pure stand. Relative yield total (RYT) of a given mixture is *R* summed over each of its components (Silvertown 1982). Data were subjected to analysis of variance using Statgraphics 2.1 (STSC, Rockville, Maryland) computer program.

Results

The behaviour of cultivars in pure stands and in mixtures was similar with high and low soil nitrogen availability. Only the fraction of grain protein showed a nitrogen × mixture interaction. Nitrogen fertilizer significantly affected the total aerial biomass production, grain yield, grain number per m^2, number

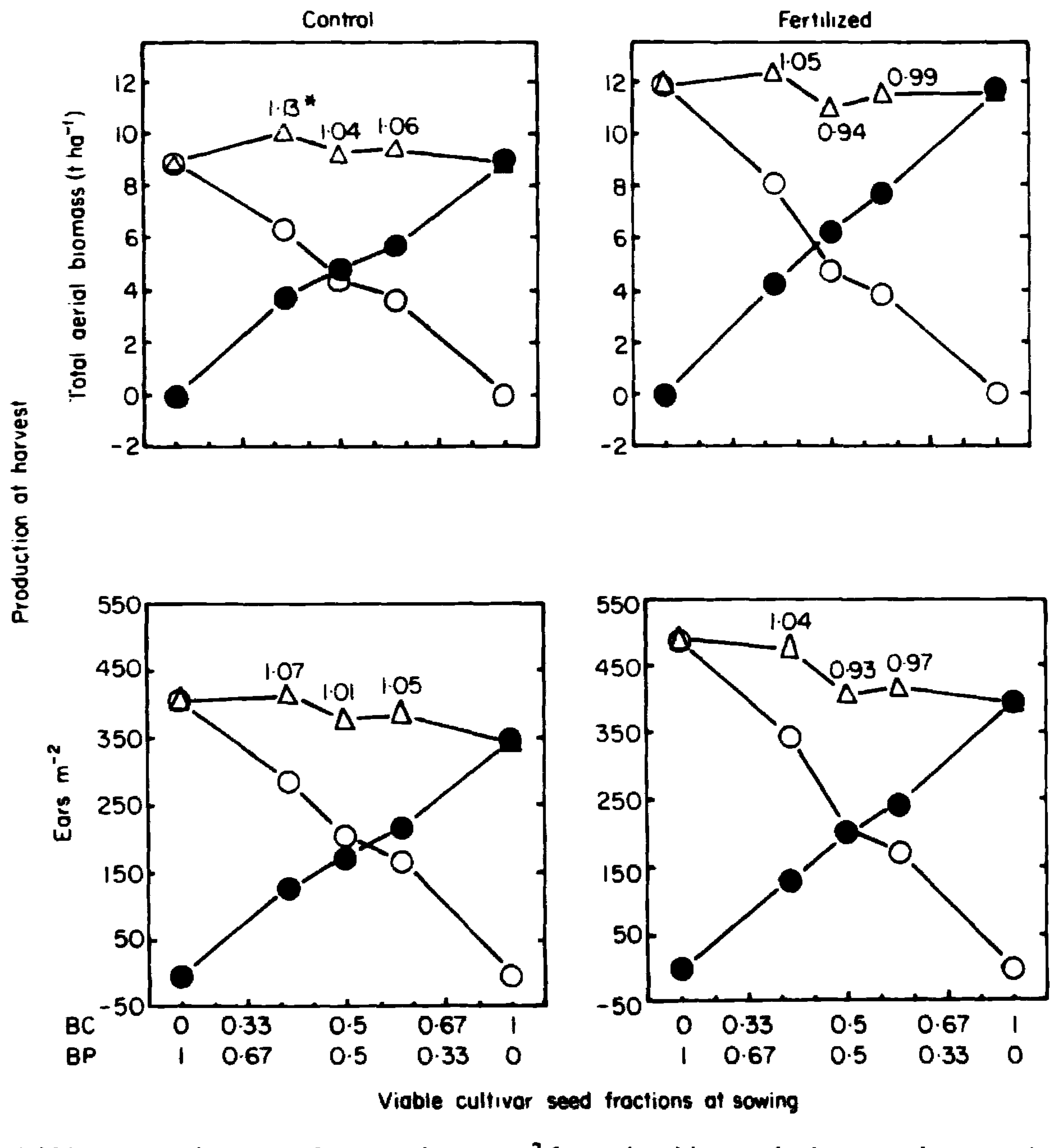

Fig. 1. Total aerial biomass production and ear number per m^2 for each cultivar and mixture under control and fertilized condition. (●) Buck Cencerro; (○) Buck Pucará and (△) mixture. Numbers next to the triangles indicate relative yield total (RYT) for Mixtures II, III and IV (means of four replicates). Values followed by * are significantly different from expected (RYT = 1) according to LSD test at $P = 0{\cdot}05$.

Table 2. Average tiller weight (AWT), harvest index (HI), grain protein content and protein per unit area of each 'mixture' under control and fertilized condition. Values are means of four replicates. Within each column, the values followed by the same letter do not differ at $P<=0{\cdot}05$, according to LSD test. Means of each variable under both conditions are also given

Mixtures				Protein	
BP	BC	AWT (g)	Harvest index	(%)	(Kg ha^{-1})
Control					
100	0	2·21b	0·48a	10·33c	442a
67	33	2·46ab	0·43b	11·12ab	482a
50	50	2·44ab	0·42b	10·94abc	418a
67	33	2·45ab	0·44ab	11·31ab	469a
0	100	2·64a	0·44ab	11·64a	451a
Mean		2·44	0·44	11·07	452
Fertilized					
100	0	2·43b	0·48a	13·60a	780a
67	33	2·61ab	0·43b	13·01a	676b
50	50	2·74ab	0·41b	13·41a	607b
67	33	2·76ab	0·43b	13·41a	666b
0	100	2·96a	0·43b	13·01a	652b
Mean		2·70	0·44	13·29	676

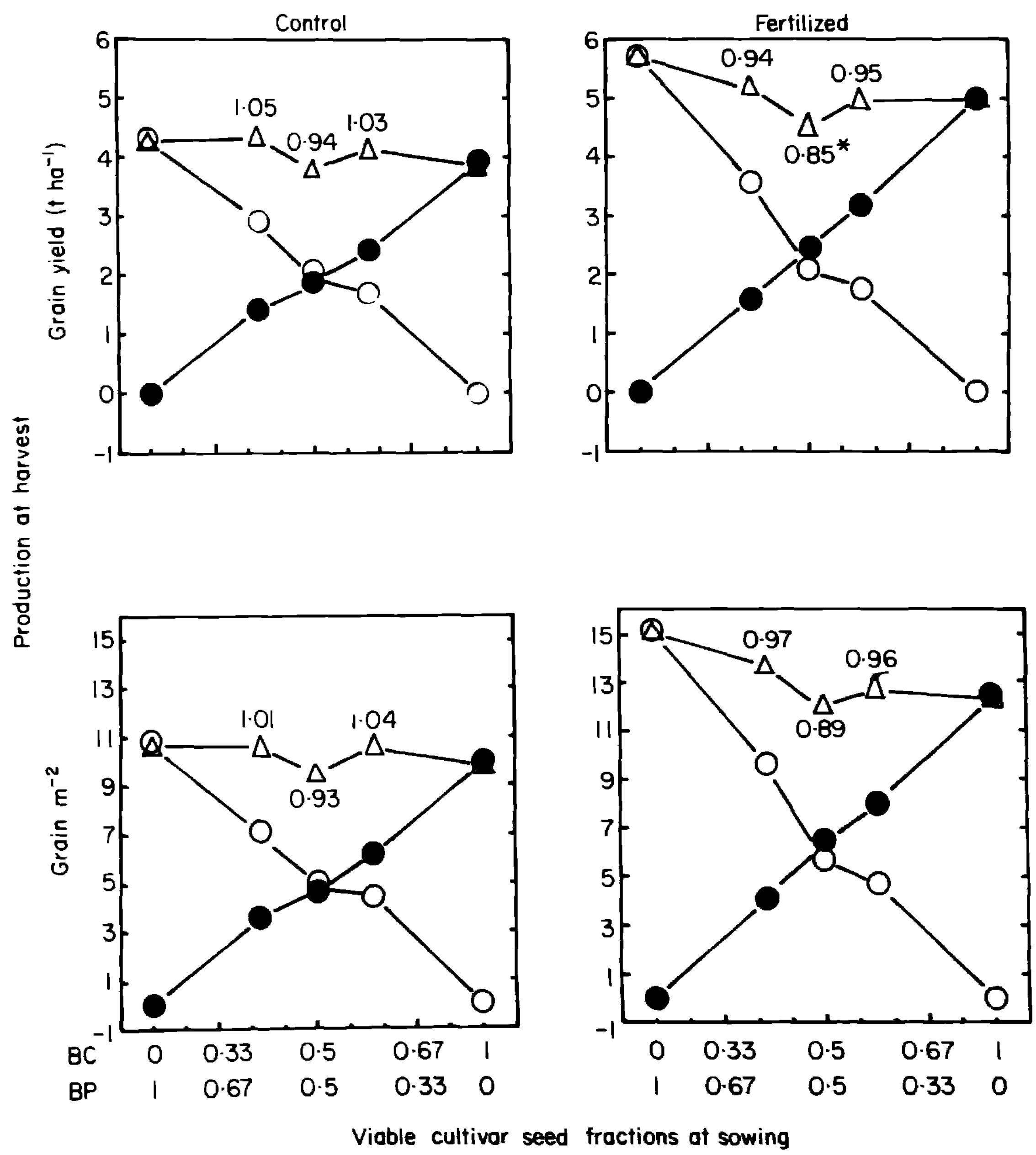

Fig. 2. Grain yield and number (below) at harvest for each cultivar and mixture under control and fertilized condition. (●) Buck Cencerro; (○) Buck Pucará and (△) mixture values. Numbers next to the triangles indicate relative yield total (RYT) for Mixtures II, III and IV (means of 4 replicates). Values followed by * are significantly different from expected (RYT = 1) according to LSD test at $P = 0{\cdot}05$.

of ears per m^2, average weight per tiller, fraction of grain protein and the grain protein production per ha, but not the harvest index (Table 1). However, for an appropriate discussion of the results, the behaviour of cultivars and mixtures under each fertility condition are presented separately.

Total aerial biomass production did not differ between cultivars growing in pure stands in either of the fertility treatments (Fig. 1). Mixture II (BP 67% and BC 33%) showed a total aerial biomass production 8% higher than the most productive cultivar (BP) under non-fertilized conditions. It also produced more biomass than either of the component cultivars under fertilized conditions; however, the difference was only significant at 10% probability. Under fertilized conditions, Mixture III showed a statistically lower biomass production with a RYT = 0·94.

The RYT for ears showed a similar pattern of variation to that for biomass production. The number of ears per m^2 at maturity was higher for BP than BC in pure stands (Fig. 1). In Mixture II (BP 67%: BC 33%) the number of ears per m^2 was similar to BP in pure stands. Average tiller weight of BC was 19 and 22% higher than that of BP in pure stands for control and fertilized plots respectively (Table 2). The differing production of ears per m^2 at harvest (reflecting different tillering ability) between the cultivars under pure stands, was compensated by tiller weight differences, which explains their similar biomass production in pure stands.

Although grain yield was increased significantly by N fertilization, cultivars and mixtures showed differences in both fertility treatments (i.e. there was no nitrogen × mixtures interaction: Fig. 2). The grain yield of Mixtures II and IV was higher than that of pure stands under non fertilized conditions. Grain yield of Mixture III was lower than expected (RYT = 1) under fertilized conditions (RYT = 0·85). Grain number per m^2 showed a high positive correlation (r^2 = 0·95) with grain yield. The RYTs for grain number were consequently similar to those for grain yield (Fig. 2).

The harvest index was higher in the higher yielding cultivar (BP) and, under both fertility conditions, the presence of BC within the mixtures diminished it markedly, even in Mixture II where BP was at 67% (Table 2). The highest biomass production of Mixture II was not associated with a higher grain production.

The effect of mixing on the grain protein content was influenced by the level of nitrogen fertilization (significant nitrogen × mixture interaction, Table 1). The protein content was high and did not differ between cultivars or mixtures under fertilized conditions. Nevertheless, in control plots (without N) the protein content of BC was 9% higher than that of BP. The grain protein content of the mixtures was similar to that of BC in pure stands and higher than expected. Under non-fertilized conditions Mixture II showed a grain yield similar to that of the better yielding cultivar (BP), and a grain protein percentage similar to that of the cultivar with better grain quality (BC). Protein production (Kg ha^{-1}) showed a high positive correlation (r^2 = 0·82) with grain yield.

Discussion

The results of this study suggest first that a mixture of two wheat cultivars can produce a higher total aerial biomass than is produced by each cultivar growing in pure stands; secondly, that this increase in production may result in a grain yield similar to that of the better yielding cultivar with an improved grain quality (protein content); and thirdly, that this mixing effect could be different for different proportions of mixture components and nitrogen availability.

According to the model proposed by de Wit (1960), and recently for cultivar mixtures by Stützel & Aufhammer (1990), the biomass yield of each component in a mixture is strictly proportional to the share of environmental resources it can acquire. Under this assumption, it can be expected that the proportional increase in the yield of one mixture component will tend to equal the proportional decrease in that of the other, since only compensatory effects can occur between competing genotypes. Nevertheless, our results showed a higher RYT than expected for biomass production for one of the mixtures in control plots (without N), indicating an overcompensatory effect.

This could be due to the cultivars' morphological and/or physiological differences, and suggests that two potential effects in the interaction of plant genotypes within a mixture should be recognized, namely competition for common resources, and an increase in potential resource availability. When the cultivars used in a mixture are agronomically identical it could be expected that they compete strongly for the same resources, and that the mixtures do not yield more than the better yielding cultivar (Simmonds 1962). In a monoculture, and especially in self-fertilizing species such as wheat, all the genotypes utilize the same resources at the same time. On the other hand, in a mixture of genotypes, the total potential resources may increase. The spatial and/or temporal availability of light, water and nutrients may be explored and exploited differentially by the different genotypes.

Soil resources (N and water) could be important factors for mixture performance (Trenbath 1974). Differences in the pattern of root distribution within the soil have been found (Lupton *et al.* 1974) among wheat genotypes (old tall and modern semi-dwarf cultivars). An improved harvest index in modern varieties in Australia (Siddique, Beldford & Tennant 1990) has been associated with a reduced investment of dry matter in the root system. Because the cultivars used in the present study differ in their harvest index, they would be expected to show a different pattern of root growth. Mutual avoidance by adjacent root systems could lead to a late-developing root system occupying deeper soil layers in mixtures than in monocultures. In this case the RYT value may be expected to exceed unity (Berendse 1979), since the resources available to the mixture have increased. The observed tendency for a better performance of Mixture II in unfertilized plots suggests a better utilization of N by the mixture when it was the limiting factor. Moreover, the higher biomass production of mixtures was apparently minimized when N was applied. Mixing effects were also found to be dependent on growing conditions, particularly nitrogen availability, by Aufhammer *et al.* (1989). In that instance, positive mixing effects were also obtained under 'suboptimal' nitrogen conditions.

This suggests that light was not the principal resource competed for within the mixture. This is in agreement with Trenbath (1972, cited by Trenbath 1974) who predicted only a very small advantage in gross photosynthesis when modelling mixtures of wheat cultivars with contrasting leaf inclinations. The higher grain protein content in Mixture II may have resulted from an increase in biomass production and a decrease in harvest index that permitted a greater nitrogen supply to the grain. This behaviour is consistent with the fact that 70–90% of nitrogen in the grain comes from that previously accumulated in vegetative structures (Austin *et al.* 1977; Kramer 1979; Scholz 1984).

Although our results suggest that a mixture of two wheat cultivars can produce a higher total aerial biomass than a monoculture, this is not necessarily associated with a higher grain yield. Within a mixture, the interference between different cultivars may cause a different dry matter partition from that in pure stands. Mixture II showed a decrease in harvest index compared with pure cultivar, indicating that a higher proportion of resources was allocated to competitive structures (stems and leaves). This suggests that differences among cultivars may increase the use of resources but, depending on the proportion and on the environmental conditions used, the effect of competition may be more important. In the present study, Mixture II produced more but Mixture III less biomass and grain yield. This indicates that, in order to obtain a highly productive mixture, the optimal combination will depend not only on the choice of the components, but also on their relative proportions. This was not taken into account by Trenbath (1974), who reviewed only mixtures sown at 50:50 proportions.

Our results suggest that the existing differences among some wheat genotypes (in morphology, architecture, physiology, etc.) could result in a different exploitation and utilization of resources. Mixtures of wheat cultivars can be used as an alternative to improve crop production in a low input agriculture. This could result in lower economic and environmental costs, while maintaining a more stable grain production, which may be especially important in the context of the extensive literature on disease reduction in cultivar mixtures (Borlaug 1959; McKenzie & Grant 1980; Knott & Mundt 1990). A minimum of uniformity is needed to sow, harvest and process wheat and other crops. The cultivars selected in this experiment had a similar crop cycle and height, and the mixtures do not show problems at sowing or harvest. Moreover, there should not be problems in the processing of mixtures of wheat cultivars because millers blend them in the silos. Because modern high yielding cultivars have a high harvest index and, consequently, a high grain/straw proportion, few residues are left in the field after a crop cycle. Because of the importance of the soil organic matter in a low input agricultural system, the greater biomass production of mixtures, achieved while maintaining grain yield and protein content, is another important benefit gained from this alternative agricultural technology.

The present study suggests that the use of mixtures of contrasting cultivars is an ecologically promising alternative method for optimizing wheat production in a low input agricultural setting. However, because of the limitation of the field trial, the generality of its results should be tested on a large scale, in more environments and with more cultivars.

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