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PERFORMANCE OF TWO WHEAT CULTIVARS IN 1:1 MIXTURES WITH RESPECT TO GRAIN YIELD AND YIELD COMPONENTS*

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Abstract

Plant competition studies with respect to grain yield and yield components were made on two spring wheat cultivars, Highbury and Sappo grown in monocultures and in 1:1 mixtures at a range of densities (237 to 920 plant per sq. meter) and in different planting patterns using systematic fan design.

Number of spikes and spikelets per plant and number and weight of grains per plant varied with the density for both the cultivars. Number of spikes was the most plastic and individual grain weight, the least plastic of the characters affected by density. Generally, Sappo was more vigorous and aggressive. Its aggressivity, measured for yield components, increased with increasing degree of mixing of the cultivars.

Planting arrangements significantly affected the performance of cultivars but the differences did not always follow the trend from maximum (1x1 planting pattern) to minimum (8x8 arrangement). Individual grain weight was the least affected by any of the planting arrangements.

Introduction

Grain yield is the product of three main components: the number of fertile tillers or spikes per unit area, the mean number of grains per spike and the mean weight of individual grains. The mean number of grains per spike is the product of the number of spikelets per spike and the number of grains per spikelet. The relationship between these components may differ with different cultivars and different components may vary in

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their response to environmental factors such as light, temperature and the availability of nutrients. The number of spikes is mainly determined by the extent of tillering before inflorescence initiation, whereas the intensity of light, the level of available nutrients and the genotype (cultivar) are the main factors determining the maximum number of tillers per plant or unit area (Evans *et al.*, 1975). There are several ways by which plants may attain the same final grain yield. In some instances, spike number may be the major component, in other cases grain number per spike might be dominant (Apel & Lehman, 1967; Thorne *et al.*, 1968; Syme, 1970) and yet in other examples, individual grain size might be the important component (Simpson, 1968).

Usually all the grain yield components show plastic responses to the effect of density. Generally the effect is greatest on the number of tillers per plant as this is the component which is determined during early stages of plant development. Individual grain size is determined after all other yield components have already been determined, and by that time, most of the adjustments to the effect of density have already occurred. Consequently, this character is the most stable of all the yield components in the face of density (Clements *et al.*, 1929; Harper, 1977).

Agronomists have mostly been concerned with the effect of density on the production of grain yield on a per unit area basis and any mean plant yield obtained by dividing the yield per unit area by density will certainly obscure the interplant variations which occur in pure and mixed stands (Harper, 1963). Thus to study the effect of density on individual plants is of great importance. The study reported in the present paper concerns the response of two wheat cultivars grown in 1:1 mixture against interference and plant competition with respect to grain yield and yield components. The object of the present investigations was to demonstrate the effect of mixing on the relative aggressivity of two cultivars, namely, Sappo against Highbury and particularly to study the performance of the individual plants.

Materials and Methods

Thirty-six to forty hours old uniform seedlings selected from pregerminated wheat grains of cultivars Highbury and Sappo in a 1:1 mixture were planted in a cold Dutch-light glass-house in the School of Plant Biology, University College of North Wales, Bangor, Gwynedd, U.K. The planting was done in May 1979 in a steam sterilized flour using a template and then seedlings covered with a one cm layer of John Innes No. 1 compost. Twenty plots, each measuring 105.3 x 63.4 cms, were marked out. In each plot, seedling to seedling distance from 3.6 to 7.0 cms was arranged in such a manner that individual plot carried a Systematic Fan Design type Ia of Nelder (1962). With this seedling distance, five main treatments of 1:1 mixture arrangements became possible, namely clump sizes of 1x1, 2x2, 4x4, 6x6 and 8x8. In case of 1x1 pattern, one plant of each cultivar alternated with the other. In the 2x2, two plants of each cultivar alternated with each other and so on. All fans consisted of 16 complete radii and 12 density arcs (Figure 1). The two outer arcs on either sides were considered as border. Consequently, the eight central density arcs and 16 complete radii in a fan comprised of 128 plant positions and subsequently each half fan had 64 plant positions for each cultivar. Thus 128 individual plants (64 plants per cultivar), growing on eight central density arcs and 16 complete radii in each fan, were available for detailed plant competition studies for grain yield and yield components.

In order to minimize the variation due to the arrangement of the fans in the glasshouse, all the treatment fans were randomly made to face northwards and southwards, respectively in two replications. During July 1979, plants were provided with supports using 10 cm^2 plastic net which was raised from time to time as the plants grew. Harvesting was done in October 1979. Each of the 128 plants was harvested separately. After threshing, following data were recorded on per plant basis:

Number of spikes (fertile tillers) per plant.
Number of spikelets per plant.
Number of grains per plant.
Grain weight per plant (gms).
Number of spikelets per spike.
Number of grains per spike.
Number of grains per spikelet.
Grain weight per spike (gms).
Individual grain weight (mg) obtained by dividing the total grain weight per plant by the total number of grains per plant.

Derivation of data from the fan designs

Data describing the area per plant (A), density (D) and distance to neighbours of the plants in the fan designs are obviously inherent of the design (Nelder, 1962). In this experiment, the data required for area per plant (A) in each density arc (n) has been obtained using Bleasdale's (1967) model. Thus, the area per plant (A) and the number of plants per square meter at various densities ($D = 1/A$), as calculated, are given in Table 1.

Statistical analysis

The data handling and statistical analysis was carried out on the University College of North Wales, Computer Science Laboratory System DEC-10. Means of each density arc and radii were calculated for each cultivar separately. Data for each character was tested for its normality, and where necessary, was transformed into $\log_e$ before performing the analysis of variance.

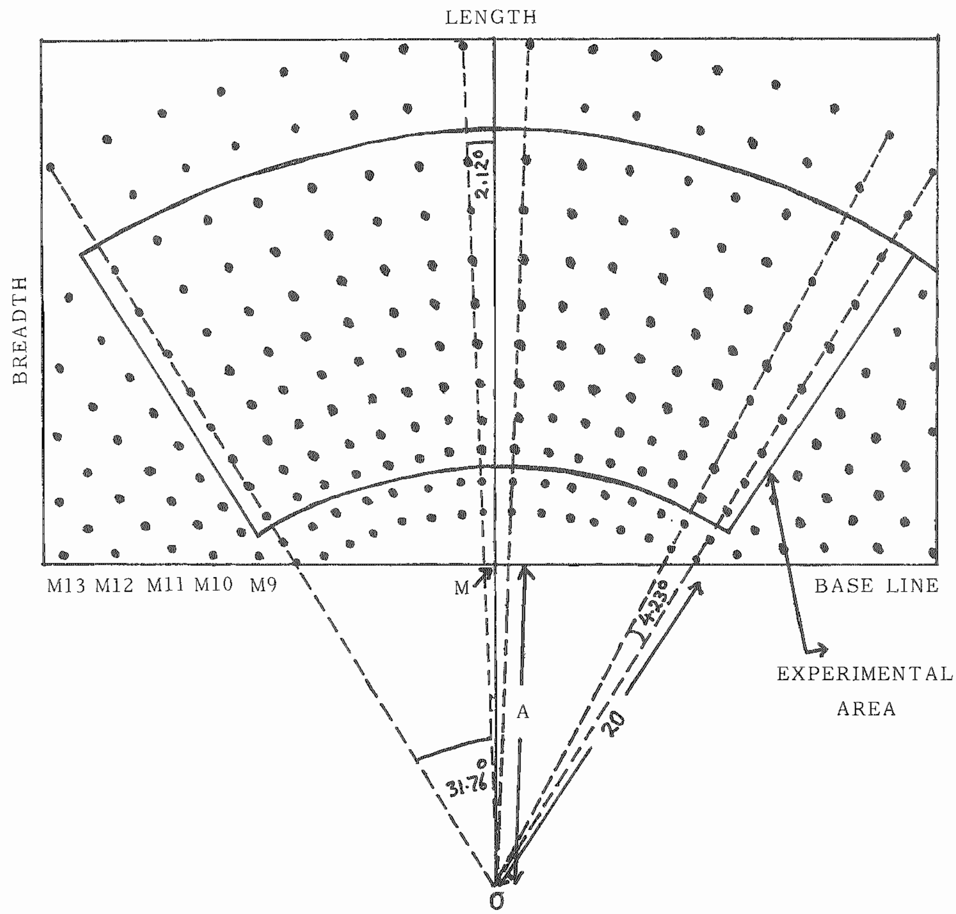

Fig. 1. Systematic fan design Ia (Nelder, 1962) showing the arrangement of spacings and the individual plant positions.

1. θ = Angle between radii 4.23° or 0.0739 radians.
2. Half angel of the fan = 31.76°
3. O = The centre of origin of the fan
4. M = The point at which the central radius line cross the base line at right angel, the next radius crosses at M_1, the next at M_2 and so on.
5. A = 38.45 cm being the shortest distance between points 'O' and 'M'.
6. Length of the rectangular plot = 107.33 cm
7. Breadth of the rectangular plot = 63.43 cm

Table 1. The area per plant and number of plants per square meter at each density as calculated from the fan design.

Arc number	Density (D)	area per plant (cm^2)	Number of plants per density
1. (guard arc)	guard arc	13.0	772
2.	D1	15.03	665
3.	D2	17.04	575
4.	D3	20.02	495
5.	D4	23.4	427
6.	D5	27.1	368
7.	D6	31.5	318
8.	D7	36.5	274
9.	D8	42.3	237
10. (guard arc)	guard arc	49.0	204

A four-way factorial analysis of variance was carried out on each of the nine characters under study to examine the effect of density and planting arrangements on both the cultivars.

Results and Discussion

The effect of density on the performance of two cultivars, viz., Highbury and Sappo with respect to grain yield and yield components is demonstrated in Table 2. The performance of these two cultivars under different planting patterns is given in Table 3. The Least Significant Differences estimates as obtained from the analyses of variance of data in Tables 2 and 3, from a four replicated randomized block design, are presented in Table 4. The results indicate the comparative performance of the two cultivars in various plant densities and planting patterns.

Table 2. Effect of plant densities on yield and yield components of two wheat cultivars grown in 1:1 mixture.

Character	D1	D2	D3	D4	D5	D6	D7	D8	Mean
Spikes per plant	1.18 2.25	1.08 1.99	1.07 2.16	1.13 2.12	1.24 2.20	1.47 2.35	1.69 2.88	2.15 2.36	1.38 2.42
Spikelets per plant	17.5 39.0	16.0 34.8	16.1 37.1	17.1 36.0	18.4 38.8	21.4 42.2	25.4 51.7	32.7 60.9	20.6 42.6
Grains per plant	44.7 77.7	41.5 68.5	41.5 69.6	43.7 69.5	46.5 76.5	53.3 82.0	63.6 105.2	79.7 126.7	51.8 84.5
Spikelets per spike	15.4 17.6	16.2 18.5	14.6 18.3	15.4 17.4	15.7 18.3	14.8 17.6	14.7 17.5	16.4 18.0	15.4 17.9
Grains per spike	38.8 34.9	39.2 34.8	39.2 32.3	39.5 33.0	38.2 34.5	36.9 35.0	38.5 36.5	37.6 38.2	38.5 34.9
Grain per spikelet	2.4 2.2	2.5 2.3	2.6 2.0	2.8 2.1	2.5 1.9	2.8 1.8	2.6 2.3	2.6 2.2	2.6 2.1
Grain weight per plant	1.03 2.41	0.90 2.11	0.90 2.15	0.95 2.18	1.03 2.40	1.18 2.56	1.42 3.23	1.27 3.83	1.16 2.61
Grain weight per spike	1.01 1.17	0.82 0.97	0.84 1.19	0.79 1.08	0.82 1.22	1.00 0.96	0.80 1.05	0.96 1.16	0.88 1.10
Individual grain weight	22.0 29.2	23.2 30.4	24.8 31.6	23.5 30.8	20.2 32.6	21.8 32.8	20.6 29.6	23.1 31.0	22.4 31.0

Note: The first reading under each column refers to cultivar Highbury and the second to Sappo.

Sappo produced significantly more spikes per plant than Highbury. As densities increased, the spikes per plant decreased for both the cultivars. Highbury was significantly affected by planting patterns where more number of spikes per plant were observed in 2x2 pattern than in the 1x1 and 6x6 arrangements.

Sappo produced significantly more spikelets per plant than Highbury. At lower densities, the number of spikelets per plant were more. Comparatively, 1x1 and 6x6 planting patterns had fewer spikelets than 4x4 and 8x8 arrangements.

Table 3. Effect of planting patterns on yield and yield components of two wheat cultivars grown in 1:1 mixture.

Charater	1x1	2x2	4x4	6x6	8x8
Spikes per plant	1.26 2.45	1.52 2.32	1.39 2.45	1.29 2.40	1.41 2.45
Spikelets per plant	19.0 41.6	20.7 41.5	20.9 43.1	19.9 39.5	22.5 47.1
Grains per plant	48.2 85.0	48.6 80.9	55.7 93.7	48.5 76.6	58.1 86.2
Spikelets per spike	15.4 17.8	16.0 18.7	14.4 18.2	15.5 17.8	15.7 18.5
Grains per spike	38.7 34.7	33.8 35.1	40.9 37.7	37.7 32.1	41.2 34.9
Grains per spikelet	2.60 2.20	2.40 2.00	2.70 2.20	2.50 2.00	2.60 1.90
Grain weight per plant	1.01 2.42	0.94 2.37	1.38 3.06	1.06 2.31	1.41 2.89
Grain weight per spike	0.82 0.99	0.68 1.04	1.01 1.23	0.82 0.97	1.00 1.17
Individual grain weight	21.2 28.3	19.7 29.5	24.6 32.8	21.5 29.8	24.1 33.5

Note: The first readng under each column refers to cultivar Highbury and the second to Sappo.

Number of grains per plant was higher in Sappo as compared to Highbury. Apart from slightly higher values at density D1 than at D2, there was a marked inverse relationship between the number of grains per plant and the density. Plants in 4x4 and 8x8 arrangements produced more grains than did plants in the other arrangements.

The number of spikelets per spike was higher in Sappo than in Highbury. Densities and planting patterns did not affect the number of spikelets per spike in either cultivar.

Table 4. L.S.D. values at 5% level for various plant densities and planting patterns of two wheat cultivars for yield and yield components.

Character	Plant densities			Planting patterns		
	cultivar means	density means	cultivar x density	cultivar means	pattern means	cultivar x pattern
Spike per plant	0.034	0.103	0.165	n.s.	(0.120)	n.s.
Spikelets per plant	(0.034)	(0.106)	n.s.	n.s.	(0.076)	n.s.
Grains per plant	(0.034)	(0.105)	n.s.	n.s.	(0.075)	n.s.
Spikelets per spike	0.85	n.s.	n.s.	0.85	n.s.	n.s.
Grain per spike	1.19	5.89	n.s.	2.69	4.29	n.s.
Grains per spikelet	n.s.	n.s.	n.s.	0.051	0.112	n.s.
Grain weight per plant	(0.048)	(0.148)	n.s.	n.s.	(0.105)	n.s.
Grain weight per spike	n.s.	n.s.	n.s.	0.044	0.160	0.098
Individual grain weight	n.s.	n.s.	n.s.	0.76	1.67	n.s.

Notes: n.s. means non-significant.
The values in the brackets imply that the data was transformed into $\log_e$ and then anova carried out.

Plants of Highbury had 3.5 grains per spike more than plants of Sappo. The only significant difference due to density was for cultivar Sappo where the number of grains per spike was less at D_3 than at D_8. Cultivar Highbury produced fewest grains per spike in planting pattern 2x2 and Sappo had fewer in 6x6 than in 4x4 pattern.

Cultivar Highbury produced more grains per spikelet than Sappo. Density did not affect this character in either cultivar but the effect of planting pattern was significant at 5% level.

Cultivar Sappo yielded more than twice the weight of grains per plant than Highbury and there was an inverse relationship between density and grain weight per plant. Both the cultivars produced significantly higher grain yields per plant in the 4x4 and 8x8 planting patterns.

Cultivar Sappo produced higher mean grain weight per spike than Highbury. Density did not affect this character in either cultivar. The most prominant effects of planting pattern were the higher mean grain weights per spike for both cultivars in the 4x4 and 8x8 arrangements.

The mean individual grain weight was higher in Sappo than in Highbury but there was no effect of density. Individual grain weight was higher in plants in the 4x4 and 8x8 than in other planting patterns.

A general review of the performance of the cultivars used in the present study showed that the number of grains per spike and number of grains per spikelet were generally lower in Sappo than in Highbury. This might be due to late elongation of Sappo's inflorescence which could have caused a decrease in the number of fertile florets per spikelet. Evans *et al.*, (1975) also concluded that the conditions that accelerate floral induction tend to reduce spikelet number by hastening the formation of the terminal spikelet. Once the terminal spikelet is formed, environmental conditions no longer influence spikelet number, but they may affect the number of florets differentiated within each spikelet. The higher number of grains per spike in Highbury was due to higher number of grains per spikelet which in turn is related to higher number of fertile florets per spikelet. Perhaps this cultivar was comparatively slower in elongating the inforescence than Sappo. Bingham (1967) suggested that increase in grain number would involve an increase in either growth rate of developing ears or in the duration of ear development before anthesis.

The weight of individual grains is mainly determined by conditions after anthesis (Bingham, 1967; Evans *et al.*, 1975). Cultivar Sappo developed relatively larger grains than Highbury. Important factors determining grain size are the rate and duration of grain filling. Sappo is relatively later maturing than Highbury (Mann, 1978). Asana & Joseph (1964) found that the grains of 'PBC-281' wheat cultivar were larger than those of 'NP-720' because of longer period of grain filling. Spiertz (1974) and Sofield *et al.*, (1977) also reported that larger grains are associated with both faster growth and longer period of grain growth due to lower temperatures during this stage. The weight of individual grains in Sappo was also higher perhaps because of lower number of grains per spike.

It has been reported by Bingham (1967) and Evans *et al* (1975) that final grain size depends, to some extent, on the number of grains per spike; the lower the number of grains, the greater the size of individual grains.

The factorial analysis of variance presented in Table 5 explains the overall effect of densities and planting patterns. Spacing has significant effect on the development of wheat plants and their yield (Engledow, 1925; Clements *et al.*, 1929; Donald, 1954; Quinlan, 1963; Puckridge & Donald, 1967). Plants growing at close spacings (high densities) meet stress from their neighbours early in their development whereas plants at lower densities do so only when they have grown larger. In the present studies number of spikelets per spike, number of grains per spike, number of grains per spikelet, grain weight per spike and individual grain weight were stable and not affected by density (Table 5). Many workers have observed the stability of these characters in wheat with respect to response to density. Fisher (1978) reported that individual grain weight is relatively stable character and is rather insensitive to competition. Clements *et al.*, (1929) reported that number of spikelets per spike was relatively stable over range of densities. However, Puckridge & Donald (1967) and Puckridge (1968) reported that the number of spikelets per spike showed a decline with increase in density which was due to high light interception at high densities (Evans *et al.*, 1975). Engledow (1925), making a two-variety comparison at different spacings, noted difference in the plasticity of the number of grains per spike. Quinlan (1963) and Quinlan & Sagar (1965) also observed that the number of grains per spike was relatively more stable.

The characters which showed response to density were number of spikes, spikelets and grains per plant and grain weight per plant (Table 5). For all these characters, there was a twofold difference in the performance at D_2 compared with D_8 (Table 2). All these differences can be clearly related to one main variable the number of fertile tillers per plant. Even the weight of grains per plant is clearly determined by the effect of density on the number of fertile tillers per plant. According to Rawson (1971), density stress affects the potential spike number upto the time the flowers are initiated, for after flower initiation, the number of tillers scarcely increases further. Present results are in conformity with the above findings.

As far as the overall effect of planting pattern is concerned, the spatial arrangement is the function of the proportion in which the cultivars are mixed. In the design of the present experiment, the degree of mixing of the cultivars decreased in the sequence 1x1 2x2 4x4 6x6 8x8, the latter pattern being close to monoculture. The working hypothesis was that some characters at least would show trend related to this sequence. Cultivar Sappo (the aggressor) might have been expected to perform relatively best in the 1x1 pattern and least well in the 8x8 arrangement as compared to Highbury and *vice versa.* The analysis of variance (Table 5) showed that planting pattern was highly significant for all the characters except number of spikes per plant and number of spikelets per spike.

Table 5. Mean squares from the analysis of variance for nine characters of two wheat cultivars studied at eight densities and five planting patterns in 1:1 mixture at the University College of North Wales, Bangor.

Source of variation	D.F.	Spikes per plant ($\log_e$)	Spikelets per plant ($\log_e$)	grains per plant	Spikelets per spike	Grains per spike	Grain per spikelet ($\log_e$)	Grain wt. per plant	Grain wt. per spike	Individual grain weight
Blocks	3	0.278***	0.053	0.042	56.250*	173.981**	0.024	0.522***	1.051***	345.097***
Density (D)	7	1.782***	2.015***	2.038***	2.112	22.260	0.005	2.167***	0.033	3.390
Pattern (P)	4	0.052	0.261***	0.375***	28.689	275.942***	0.143*	1.632***	0.923***	277.669***
D x P	28	0.016	0.009	0.012	6.010	11.461	0.197	0.015	0.011	5.952
Cultivars (C)	1	27.077***	43.039***	18.970***	535.542***	1038.967***	4.862***	45.221***	3.718***	5870.017***
D x C	7	0.072**	0.043	0.014	1.588	61.479*	0.022	0.028	0.017	11.294
P x C	4	0.112***	0.024	0.055	21.780	144.429***	0.057	0.090	0.120*	18.149
D x P x C	28	0.022	0.012	0.019	6.596	19.181	0.023	0.026	0.023	4.602
Error	237	0.023	0.023	0.024	14.908	29.454	0.054	0.048	0.041	11.918

* Significant at 5% level ** Significant at 1% level *** Significant at 0.1% level.

Significant differences were found between patterns but much more often both the cultivars shared the high and low value points (Table 3). In other words the initial hypothesis seems to be rejected.

Grain weight per plant for each cultivar was significantly higher in the 4x4 and 8x8 patterns than in 1x1, 2x2 and 6x6. Cultivar Sappo displayed its relatively greater yield in every pattern. Individual grain weight, which was the most stable in response to density (Table 2), varied irregularly but significantly with planting pattern (Table 3). This may be due to the effect of environmental variability caused by planned treatments. The significant differences between blocks for most of the characters (Table 5) support this possibility. Kelker & Briggs (1978) also reported that wheat cultivars reacted very differently to intergenotypic mixing. They concluded that it is difficult to generalize, the effects of competition and spacing on the expression of agronomic characters of wheat cultivars and the effects on variability and mean performance of single plants appear to be specific to each genotype. Hence the stability of individual grain weight in different planting patterns may specifically be attributed to the genotypic constitution of Sappo and Highbury.

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