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Spatial Arrangement Affects Growth Characteristics of Barley-Pea Intercrops

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ABSTRACT

The effect of spatial variation in the planting arrangement on characteristics of a 50:50 barley/pea intercrop mixture was studied. The three planting arrangements were (i) complete seed mixing within rows, (ii) the two species cross drilled at right angles and (iii) alternate pairs of rows of the two un-mixed species. Pure stands of barley and peas were included for comparison. In all cases, dry matter production from intercropping was greater than that from sole crops; however, planting arrangement did have a significant effect. Land equivalent ratio (LER) values were 1.26, 1.25 and 1.16 for the mixed row, cross drilled and alternate row arrangements, respectively. The alternative row strategy produced significantly less LER value than the other two arrangements. While, there was an increase in LER values in both the component species of the mixtures, the magnitude of effect was greater with the barley (average of 30.0% increase) than it was with the peas (average of 14.8% increase). Grain/seed yields of both components of the intercrop mixtures were greater than would be expected if these were expected to yield half that of the sole crops. The increases were brought about by an increase in the number of ears m^{-2} in barley and pods m^{-2} in peas. Analysis of N uptake suggests that greater N availability for the barley component of the mixture was the mechanism responsible for the increased barley yields. Improved pea growth is likely to have arisen from the support offered by the barley plants, which was greatest in the mixed and cross rows, but least in the pairs of alternate rows.

Key Words: Barley; Peas; Intercropping; Planting arrangement; Grain yield; Dry matter; Tissue nitrogen

INTRODUCTION

Intercropping, the growing of two or more crop species together on the same land has long been a strategy used in tropical agriculture (Vandermeer, 1989). In temperate agricultural systems, there has been increasing interest in intercropping cereal/legume mixtures both for forage production (Anil *et al*., 1998; Ghanbari-Bonjar & Lee, 2002) and for grain production (Bulson *et al*., 1997; Haymes & Lee, 1999). Benefits have been attributed to greater long term yield stability, more efficient utilization of finite resources (nutrients, water & light) and reduced weed and disease pressure.

Effectiveness of intercropping systems varies with a range of factors, including the component crop species and the relative proportions of the components in the mixture. Within any one system, however, another factor is likely to influence the relative performance of the species is the spatial arrangement of the components. Such arrangements may consist of complete mixing of the species within the rows, alternate rows of pure species, alternate blocks of two or more rows of pure species or even cross-drilling rows of pure species at right angles to each other. While, there is much reported work on a range of intercropping mixtures and the relative proportions of these mixtures, there is little on the planting arrangements of the various components and the literature is inconclusive as to the most efficient arrangement. For example, Chen *et al.* (2004), Lauk and Lauk (2008) and Aynehband *et al.* (2010) concluded that mixing of crop species within rows to be the best arrangement for barley/peas, oats/peas and maize/amaranth intercrops, respectively. In contrast, Martin and Snaydon (1982) and Dubey *et al.* (1995) found that alternate row systems produced highest yields for barley/beans and sorghum/soybean mixtures, respectively. Zaman and Malik (2000) observed more grain yield and net income of maize/ricebean intercrop, when sown in double row strips. However, Sesame (Bhatti *et al.*, 2006) and barley (Wahla *et al.,* 2009) in a crop mixture situation appeared to be the dominant crops as indicated by its higher values of relative crowding co-efficient, competitive ratio and aggressiveness.

It is more likely that there will be different optimum planting arrangements for different intercropping mixtures, which will depend upon the relative growth characteristics

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of the component species and the mechanism of yield improvement. Indeed, such arrangements may also be influenced by season and the relative proportions of the various components within the mixture. This study was therefore undertaken to evaluate contrasting planting arrangements for barley/pea intercrops planted in 50:50 replacement series.

MATERIALS AND METHODS

A field experiment was undertaken at the University of Wales, Aberystwyth "Morfa Mawr Field Station" on a sandy loam soil of the Cegin series, having pH 5.49-5.76, extractable P 30-33 mg g^{-1}, index P 3, extractable K 133-150 mg g^{-1} and index K 2 before sowing the crop. The field had remained under grazing pasture for the previous three years. Arrangements of a 50:50 barley/pea intercrop mixture were compared following (i) complete seed mixing within rows, (ii) the two species cross drilled at right angles and (iii) alternate pairs of rows of the two un-mixed species. Pure stands of barley and peas were included for comparison.

Seed number was determined on the basis of establishing plant populations of 300 barley (cv. Hart) and 83 pea (cv. Eiffel) plants m^{-2}. Plots were 8 m long and 1.2 m wide and comprised of 8 rows at 15 cm spacing. Seed was drilled with an Oyjord drill on 30 April, 1998 at a depth of 6-7 cm although, where peas were cross drilled, these were sown by hand in 15 cm spaced rows. Fertilizer was applied before drilling at a rate of 150 kg ha^{-1} N and 75 kg ha^{-1} each of P_2O_5 and K_2O. The herbicide, Bentazone (BASF, Basagran), was applied on 31 May to control broad leaved weeds. The experiment was laid out in a randomized block design with four replicates.

Plant samples were taken from plots by digging out with the help of a hand fork at four weekly intervals during the growth period starting from 27 May until maturity on 8 September. Two rows of 0.5 m length were sampled from the 100% sole crops and 50:50 BP mixtures, leaving at least one adjacent row and 0.5 m length of row from the previous sampling area to avoid border effects. Sampling for the cross drilled plots was done by removing 2 m × 0.5 m (length-wise) rows of peas and 2 m × 0.5 m (width-wise) rows of barley. Sampling of the alternate rows was done by removing 1 m × 0.5 m row of each crop. Plants were divided into component species, counted and subsequently each separated into leaf and stem (seed heads post-anthesis). Dry weights were recorded and material analyzed for N content. At maturity, plants from two places of 0.5 m^2 areas were harvested by hand, separated into component species and for each, the components of yield determined.

All the data were analyzed by standard anyalsis of variance techniques by using MSTAT-C Software (MSTAT-C, 1988). The treatment means were compared by using least significant difference.

For mixtures, land equivalent ratio (LER) was determined as developed by Mead and Willey (1980):

Where:

$$\text{LER} = \frac{Y_{bp}}{Y_{bb}} + \frac{Y_{pb}}{Y_{pp}}$$

Y_{bb} and Y_{pp} are yields of barley and peas, respectively in pure stand.

Y_{bp} and Y_{pb} are yields of barley and peas, respectively in mixture.

The competitive ability of barley in various mixtures, relative to peas was measured as its aggressivity (McGilchrist & Trenbath, 1971), where:

$$\text{Aggressivity} = \frac{Y_{bp}}{Y_{bb} \times Z_{bp}} - \frac{Y_{pb}}{Y_{pp} \times Z_{pb}}$$

Z_{bp} and Z_{pb} are the sown proportions of barley and peas, respectively.

RESULTS

Analysis of components of yield indicate that the number of grains per ear in barley and seeds per pod in peas was un-affected by intercropping and planting arrangement, as was the individual grain/seed weight (Table I). Harvest index remained un-affected by treatment (Table I). The increased yields of the components of the intercrop species compared with expected (i.e., half the sole crop yield) were the result of a greater number of ears m^{-2} in barley and pods m^{-2} in peas. There was an indication that this effect was influenced by planting arrangement in barley, where the effect was greater in the mixed and cross drilled treatments than in the alternate rows treatment, but this was not the case for peas.

The leaf area indices of the barley grown in combination with peas were lower than a sole crop of barley, but higher than might be expected with the 50/50 replacement series (Table II). There were no differences as a result of planting arrangement. The leaf area indices of peas were smaller than those of barley and when grown in combination with barley, were similar to what might be expected from a 50/50 replacement series i.e., half the value of the sole crop. Combined leaf area indices of all the barley/pea mixtures were similar, all significantly lower than the sole barley crop, but all significantly greater than the sole pea crop.

Barley dry matter was, understandably, less when grown in combination with peas than as a sole crop however, there was a marked increase when a more realistic comparison with half the value of the sole crop is made, indicating significantly better growth (Table III). The alternate rows planting arrangement produced significantly less dry matter then either mixed or cross drilled planting arrangements. A similar pattern of response was found with the peas, but to a lesser extent, while differences between planting arrangements were not statistically significant. Total dry matter was greatest with the barley/pea intercropped mixtures planted as mixed rows or cross

Table I: Yield components of (a) barley and (b) peas, grown under different planting arrangements

(a) Barley

Planting arrangement	Ears/m²	Grains/ear[1]	1000 grain wt. (g)	Harvest Index (%)
Sole Barley	703 (352)*	23.5	36.1	47.5
Mixed within rows	461	23.7	37.7	48.5
Cross drilled	452	22.4	39.5	48.0
Alternate rows (pairs)	430	23.7	36.4	49.2
SE	23.1	0.43	2.38	1.38

(b) Peas

Planting arrangement	Pods/m²	Seeds/pod[1]	100 seed wt. (g)	Harvest Index (%)
Sole Peas	396 (198)*	3.3	26.2	38.6
Mixed within rows	232	3.2	28.9	41.7
Cross drilled	227	3.3	27.4	41.0
Alternate rows (pairs)	231	3.6	26.3	45.3
SE	14.7	0.16	0.71	3.75

Table II: Maximum Leaf Area Index (at 56 days after sowing) of barley and peas grown under different planting arrangements

Planting arrangement	Barley	Peas	Total
Sole Barley	7.41 (3.71)*	-	7.41
Sole Peas	-	2.33 (1.17)*	2.33
Mixed within rows	4.69	1.05	5.74
Cross drilled	4.99	1.24	6.23
Alternate rows (pairs)	4.45	1.11	5.56
SE	0.291	0.153	0.270

Table III: Total dry matter (g m^{-2}) of barley and peas under different planting arrangements

Planting arrangement	Barley	Peas	Total
Sole Barley	1245.0 622.5)*	-	1245.0
Sole Peas	-	873.7 (436.9)*	873.7
Mixed within rows	839.4	511.7	1351.6
Cross drilled	834.5	505.3	1339.8
Alternate rows (pairs)	752.8	487.1	1239.9
SE	27.62	28.52	27.89

*Fig. in parenthesis are half those of the values for the sole crop and represent
Fig. more comparable with the individual components of the replacement series

drilled, alternate row intercropping produced similar dry matter to the sole barley and the sole peas produced least dry matter.

Grain yields of barley and peas are given in Table IV. Average yields of the barley components (367.5 g m^{-2}) were consistently greater than those of the pea components (201.0 g m^{-2}) and the relative proportion by weight of barley to peas in the mixtures (65%:35%) was un-affected by any of the planting arrangements. Grain yield of barley, when planted in mixture with peas was significantly reduced, when compared with the sole crop, but not when compared with the yield of a similar population density of barley grown as a sole crop (i.e., half the yield of the sole crop). Amongst planting arrangements, the pairs of alternate rows yielded less than the other treatments. Grain yields of peas,

Table IV: Grain yield (g m^{-2}) of barley and peas grown under different planting arrangements

Planting arrangement	Barley	Peas	Total
Sole Barley	591.2 (295.6)*	-	591.2
Sole Peas	-	338.5 (169.3)*	338.5
Mixed within rows	406.5	213.0	619.5
Cross drilled	400.1	205.8	605.9
Alternate rows (pairs)	367.8	215.7	583.5
SE	9.88	13.21	10.94

*Fig. in parenthesis are half those of the values for the sole crop and represent
Fig. more comparable with the individual components of the replacement series

Table V: Tissue nitrogen concentration (%) of a) barley and b) peas, grown under different planting arrangements

(a) Barley

Planting arrangement	Days after sowing					
	28	56	84	112	140	
					Straw	Grain
Sole Barley	5.40	2.64	1.35	1.50	0.96	2.25
Mixed within rows	5.40	2.93	1.70	1.65	1.53	2.59
Cross drilled	5.68	3.22	1.81	1.70	1.33	2.34
Alternate rows (pairs)	5.44	2.93	1.54	1.61	1.40	2.36
SE	0.127	0.104	0.050	0.031	0.089	0.205

(b) Peas

Planting arrangement	Days after sowing					
	28	56	84	112	140	
					Straw	Seed
Sole Peas	4.90	3.79	2.78	2.63	1.06	4.16
Mixed within rows	4.95	4.08	2.71	2.66	1.11	4.01
Cross drilled	5.10	3.98	2.88	2.49	1.20	4.00
Alternate rows (pairs)	5.11	3.85	3.01	2.64	1.03	3.96
SE	0.156	0.124	0.135	0.131	0.081	0.073

Table VI: Nitrogen uptake (g m^{-2}) by barley and peas grown under different planting arrangements

Planting arrangement	Barley	Peas	Total
Sole Barley	19.5 (9.8)*	-	19.5
Sole Peas	-	19.8 (9.9)*	19.8
Mixed within rows	17.1	11.9	28.9
Cross drilled	14.9	11.8	26.7
Alternate rows (pairs)	14.0	11.3	25.3
SE	1.01	0.58	1.23

*Fig. in parenthesis are half those of the values for the sole crop and represent
Fig. more comparable with the individual components of the replacement series

when planted in mixtures were also significantly reduced, when compared with the sole crop, but increased when compared with half the yield of the sole crop. There were no significant effects of planting arrangement on the yield of peas grown with barley. Total grain yields (barley + peas) were similar to the yield of sole barley, irrespective of planting arrangement, while the yield of the sole peas was significantly lower.

The tissue nitrogen concentration of barley grown as a sole crop was significantly lower than that of the barley component of the barley/pea mixtures throughout most of

Table VII: Land Equivalent ratio values of barley-pea mixtures (at maturity) grown under different planting arrangements

Planting arrangement	LER of dry matter yield	LER of grain yield
Mixed within rows	1.26	1.32
Cross drilled	1.25	1.29
Alternate rows (pairs)	1.16	1.26

Table VIII: Nitrogen uptake (at maturity) of barley-pea mixtures grown under different planting arrangements

Planting arrangement	N-uptake		Additional N-uptake*
	($g\ m^{-2}$)	($kg\ ha^{-1}$)	($kg\ ha^{-1}$)
Sole Barley	19.8	198	-
Sole Peas	19.5	195	-
Mixed within rows	28.9	289	93
Cross drilled	26.7	267	72
Alternate rows (pairs)	25.3	253	58

*Additional nitrogen uptake of intercrops compared with sole barley

the growing period and in the straw at harvest, but not in the grain at harvest (Table V). Within the three planting arrangements, the barley in alternate rows had a significantly lower tissue N concentration than the barley in the mixed or cross drilled treatments at 84 and 112 days after sowing, although not at maturity. The tissue nitrogen concentration of the peas, either alone or in combination with barley was un-affected by any of the treatments imposed.

Nitrogen uptake by barley crops grown in mixture with peas was significantly less than that taken up by the sole crop of barley, but substantially greater than the quantity that might be expected from a 50/50 mixture combinations (i.e., half that taken up by the sole crop). Barley grown in combination with peas in alternate rows took up significantly less nitrogen than when grown in combination with peas within mixed rows (Table VI). Nitrogen taken up by the sole crop of peas was similar to that taken up by the sole crop of barley. Nitrogen taken up by the 50% peas in the mixed crops was similar to that which might be expected from 50% of the sole crop and was similar across the three planting arrangements.

Total nitrogen uptake by the mixed cropping systems (Table VI) was significantly greater than by the sole crops and comparison of the planting arrangements indicated that total nitrogen uptake by the plants, which were mixed within rows was greater than that by plants cross drilled or in alternate rows.

DISCUSSION

Differences in light penetration into the canopy is considered to influence tillering and thus constitute a mechanism for yield improvement in the mixtures, however the pattern of response recorded in present study suggests this to be un-likely. In fact, the reverse of the results were found from the various arrangements in present investigation, where the greater competition between plants arising from the mixture of plants within rows, which have had the highest plant density per length of row and the least competition from the cross drilled arrangement, which showed the lowest density per length of row. This is confirmed from the measurements of leaf area given in Table II, where the cross drills showed a LAI of 6.23 and the mixture within rows a LAI of 5.74. These differences in maximum LAI were not indicative of subsequent grain yield.

It is possible that other factors influenced the relative performance of the components of the mixture, for example, barley provided support for the pea plants allowing them to compete more effectively for light, if this were the case, the mixture within rows provided the most support and the pairs of alternative rows the least. This is consistent with the results, however the fact that such a mechanism had little effect on barley growth and reduced barley growth. It is not consistent with the results obtained, where barley growth increased, when grown in all arrangements of mixtures and to a greater extent than the pea growth was increased.

In all cases, dry matter production from intercropping was greater than that from sole crops. However, planting arrangement did have a significant effect. Land Equivalent Ratio (LER) values were 1.26, 1.25 and 1.16 for the mixed row, cross drilled and alternate row arrangements, respectively (Table VII). The alternative row strategy produced significantly less LER values than the other two arrangements. While, there was an increase in both component species of the mixtures, the magnitude of effect was greater with the barley (average of 30.0% increase) than it was with the peas (average of 14.8% increase). The greater advantage accrued by the barley component of the mixture compared with the pea is demonstrated by the aggressivity index of barley in peas. The average value of +0.152 indicated that barley was the more aggressive component of the mixture. Comparison of the drilling methods showed that the competitive ability of the barley drilled in alternate rows with the peas (0.094) was only half that of barley established in the mixed rows (0.178) or cross-drilled (0.184).

Chen *et al.* (2004), Lauk and Lauk (2008) and Aynehband *et al.* (2010) found that mixing of crop species within rows to be the best arrangement for barley/peas, maize/soybean and maize/amaranth intercrops, respectively. Zaman and Malik (2000) observed more grain yield and net income of maize/ricebean intercrop, when sown in double row strips. However, they contrasted with findings of Martin and Snaydon (1982) and Dubey *et al.* (1995), who observed highest yields for barley/beans and sorghum/soybean sown in alternate rows than mixed within row, respectively. Similarly in contrast, Martin and Snaydon (1982) found average LER values of 1.67 for barley and beans grown in alternate rows and 1.3, when grown within row mixture. This reflects the fact that in the case of the barley/peas mixture and the oat/peas mixture, the cereal was the more aggressive species, however with the barley/bean mixture, the legume was the more aggressive. Sesame (Bhatti *et al.*, 2006) and barley (Wahla *et al.*, 2009) in a crop mixture situation appeared to be the dominant crops as indicated by its higher values of relative crowding coefficient, competitive ratio and aggressiveness. There has been little work on the cross-sowing of the components of intercrop mixtures, although Siddique *et al.* (1995) observed a greater straw yield of wheat sown in cross rows compared with parallel rows or strip planting.

Grain yields of both components of the intercrop mixtures were greater than from their 50% mixture of the sole crop. LER values of 1.32, 1.29 and 1.26 were recorded for the mixed row, cross drilled and alternate row arrangements, respectively (Table VII). The mechanism that brought about the increase in yield was the increase in the number of ears m^{-2} in barley and pods m^{-2} in peas. The number of grains spike^{-1} in barley and seeds pod^{-1} in peas remained un-affected by intercropping as did the weight of individual grains/seeds. Planting arrangement also appeared to influence this factor, with cross drilling and mixture showing a greater increase than the alternative row strategy.

The mechanism of grain yield increased in both components of the mixture was the result of an increased number of shoots. Since this process was influenced by light availability, the mechanism for yield improvement may be due to efficient utilization of incident radiation. While, N availability is also known to influence tiller production and survival in cereals. It was also not considered to influence the shoot production in peas since this process is largely independent of levels of inorganic soil N. Thus, it appears that for a cereal/legume mixture of species grown as a 50/50 replacement series, where the relative height of the components of the mixture are similar a planting arrangement that provides as uniform a distribution of plants as possible appears to be most beneficial.

The greater tissue nitrogen of barley sown in association with peas compared with those of barley sown alone indicated a greater availability of nitrogen. This is likely to have arisen from the fact that the pea component of the mixture required and utilized less soil nitrogen than its equivalent 50% barley equivalent in the sole crop. As a result, more soil nitrogen was available to the barley component of the mixture. This is consistent with the findings of Jensen (1996), who suggested that the advantage of a pea-barley intercrop was due to the complimentary use of soil inorganic and atmospheric N, resulting in reduced competition for inorganic N. Chen *et al.* (2004) reported that fertilizer N increased total biomass yield and protein level in barley-pea intercrops, but high N rates decreased the LER and resulted in toxic levels of nitrate in the forage. It is interesting to make an estimation of the quantity of N fixed by the pea component of the mixture. In present study, the pea components of mixed within rows, cross-drilled and alternate rows fixed 93, 72 and 58 kg ha^{-1}, respectively (Table VIII). The total N uptake by the mixture was always greater than by the sole barley crop (Table VIII). However, almost similar quantity of N taken up by the 100% barley (198 kg ha^{-1}) and the 100% peas (195 kg ha^{-1}) suggested that either the sole crop of peas fixed no additional N and the peas utilized soil N in the same quantity as the barley or, the peas fixed some atmospheric N and took up less soil N than the barley (Table VIII). Since pink nodules (active) were observed on the root system of the pea plants. The surplus soil N would have been available to the barley plants. It has been argued in the previous publications that some of this fixed nitrogen will be made available to the cereal companion crop (Ofosu-Budu *et al.*, 1995; Lauk & Lauk, 2008; Hauggaard-Nielsen *et al.*, 2009). This additional N taken up by the mixtures varied considerably with the different planting arrangements, the within row mixture taking up an additional 93 kg ha^{-1}, the cross-drilled an additional 72 kg ha^{-1} and the alternate rows an additional 58 kg ha^{-1} (Table VIII). These differences may reflect the extent of mixing of the root systems of the component species. It has been shown that the roots of cereals sown in mixture or in cross rows with non-cereals were very close to and intermingle to a greater extent than those sown on pairs of alternate rows (Martin & Snaydon, 1982; Fujita *et al*., 1992). It is probable that barley plants have taken up a major part of the soil mineral N from any rooting zone that the component species were co-exploiting. This in itself may have increased the nitrogen fixing activity of those pea root nodules. The extent of the co-exploitation and hence the reduction of soil mineral N around the pea roots would be dependant upon the planting arrangement, with mixtures within rows showing the greater degree of intermingling and those arranged as pairs of alternate rows, the least. This is consistent with the results found here. Increased soil mineral N availability is likely to be the mechanism for the yield increase, since increased N availability will increase tiller survival in cereal plants and this was the mechanism for increase barley yields.

CONCLUSION

It may be concluded that intercropping of barley and peas increased dry matter production and yield compared with either sole crop, irrespective of planting arrangement. The mechanism for yield improvement appears to be due to greater N availability for the barley component of the mixture. Improved pea growth has arisen from the support offered by the barley plants, which was greatest in the mixed and cross rows, but least in the pairs of alternative rows.

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