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COMPARISON OF SINGLE CROPPING, RELAY CROPPING AND DOUBLE CROPPING OF SOYABEANS WITH WHEAT USING CULTIVAR BLENDS

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SUMMARY

Comparisons of single cropping, double cropping and relay cropping of soyabeans (*Glycine max*) with wheat (*Triticum aestivum*) were made at two sites in Arkansas over a two-year period. The comparisons were made using both soyabean blends and their component cultivars. In relay cropping the yields of pure lines of soyabeans were reduced by 17% compared with single-cropped soyabeans, but the yield of wheat in relay cropping was 15% less than in double cropping. Double cropping reduced the branch number, plant height, node number and leaf area of soyabeans compared with single cropping, but relay cropping reduced only node number and leaf area. Both double cropping and relay cropping gave greater land equivalent ratio (LER) values than single cropping, and double cropping gave greater LER values than relay cropping. Net returns were lowest with single cropping and greatest with double cropping. Soyabean blends gave yields similar to the mean of the component genotypes in all three cropping systems, and the net returns of blends were similar to those of the means of component genotypes.

INTRODUCTION

Soyabeans [*Glycine max* (L.) Merr.] are grown in the mid-South region of the United States either as a full-season crop or planted immediately after harvesting wheat (*Triticum aestivum* L.) in a double-cropping system. Yields of double-cropped soyabeans have been reported to be 15–30% less than those of single-cropped soyabeans, because of the shorter growing season, and unreliable amounts and timeliness of rainfall (Jeffers and Triplett, 1979). Soyabeans can also be planted into standing wheat before harvest but this relay cropping also reduces yields. For example, relay-cropped soyabeans yielded 28% less than single-cropped soyabeans in Nebraska (Moomaw and Powell, 1990) and in Kansas (Duncan *et al.*, 1990). Reinbott *et al.* (1987) found that relay-cropped soyabeans yielded 27% less than single-cropped soyabeans but found that they yielded 28% more than double-cropped soyabeans.

Cropping systems need to be evaluated economically as well as agronomically since a cropping system may reduce the yield of one component yet still increase returns. For example, Sanford (1982) tested five patterns of double-cropped

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soyabeans and found that four were more profitable than the single-cropped system. Jeffers *et al.* (1973), Graves *et al.* (1980) and Gogerty (1989) all found that the economic return from double cropping compared favorably with a full-season soyabean crop.

The main objective of this study was to compare the effects of three cropping systems (single cropping, relay cropping and double cropping) on the yield of soyabeans, and to assess the economic feasibility of the cropping systems. The second objective was to compare blends of determinate and indeterminate soyabeans with their pure line component genotypes under the various cropping systems. All previous studies of soyabean relay cropping have used pure line soyabean cultivars but blends, comprising mixtures of two or more genotypes, may stabilize yield across environments (Walker and Fehr, 1978). This yield stability might be particularly useful in relay cropping. Schutz and Brim (1967) and Schweitzer *et al.* (1986) have also reported higher yields for blends than for the average yield of the component cultivars. Walker and Fehr (1978), however, found no yield increase of blends over pure line cultivars. There are no reports of soyabean blends grown in relay-cropping systems in order to increase yield or yield stability and no reports have been found describing the use of soyabean blends formed from mixing determinate and indeterminate growth habits.

MATERIALS AND METHODS

The experiment was conducted for two years at the main Arkansas Agricultural Experiment Station at Fayetteville on a Captina silt loam (fine-silty, mixed, mesic Typic Fragiudults) and at the University of Arkansas Vegetable Substation near Kibler on a Roxana sandy loam (coarse silty, mixed, non acidic, Thermic Udifluvents). A split-plot design was used in each study with the cropping systems (single cropping, double cropping and relay cropping) constituting the main plots and soyabean genotypes (four pure lines and two blends) constituting the subplots in a randomized complete block design with three replications.

The wheat cultivar Traveler was sown at 120 kg seed ha^{-1} using a conventional grain drill. Plots were 6.1 m in length and consisted of 28 rows spaced 18 cm apart. Wheat was sown at Fayetteville on 15 October 1988 and 18 October 1989 and at Kibler on 28 October 1988 and 27 October 1989. Wheat yields were measured by harvesting the centre 14 rows trimmed to 4.9 m and harvesting was on 29 June 1989 and 28 June 1990 at Fayetteville and on 21 June 1989 and 27 June 1990 at Kibler.

Two blends of soyabeans were used, mid-maturity genotypes (Maturity Group V) and later-maturing genotypes (Maturity Group VI). In Group V one determinate genotype (Shiloh) and one indeterminate genotype (R85-362) were selected and, similarly, in Group VI the determinate genotype (B2-J) and the indeterminate genotype (R82-158) were selected. In each case a 1:1 blend was used based on number of seeds.

In all three cropping systems soyabean plots consisted of four rows 102 cm apart and 6.1 m in length. Seed was sown at 39 seeds per metre row with a hand-pushed Planet Jr drill. In the relay-cropping system, soyabeans were sown when wheat reached Feekes growth stage 11.1, approximately one month before harvest. Both the relay- and single-cropped soyabeans were planted at Fayetteville on 21 May in 1989 and 26 May in 1990; at Kibler they were planted on 23 May in 1989 and 27 May in 1990. The single-cropped soyabeans were sown under a no-till system with an application of glyphosate (N-(phosphonomethyl) glycine) at 1.12 kg a.i. ha^{-1} immediately after sowing. In the double-cropping systems, soyabeans were sown 2–3 d after the wheat was harvested. The straw was incorporated into the soil by disking prior to sowing the soyabeans. Sethoxydim (2-[1-(ethoxyimino) butyl]-5-[2-(ethylthio) propyl]-3-hydroxy-2-cyclohexen-1-one) at 1.75 litre ha^{-1} was applied to plots in both the relay-cropping and double-cropping systems, and additional hand weeding took place approximately 45 d later. Soyabeans in all treatments were furrow-irrigated with approximately 2.5 cm water whenever incipient wilting occurred during the growing season.

Measurements

The leaf area, number of branches, number of nodes, plant height, and number of fertile nodes of four randomly selected soyabean plants in one of the border rows of each plot (not harvested for yield) were measured at the beginning of pod setting (R3 (Fehr and Caviness, 1977)). In the blends, flower colour was used to identify two plants of each genotype for measurement. Plant height was recorded as the distance from the soil surface to the top of the terminal apex. Leaf area was recorded directly by passing the leaves under the light of the Lambda Area Meter (Model LI 3100). Soyabean seed yield was determined by harvesting an end-trimmed, 4.9-m section of the two centre rows of each subplot. Seed moisture was measured from each plot and the yields were adjusted to 13% moisture. Seed weight was determined from a randomly selected sample of 100 seeds. Oil and protein concentrations in the seed were obtained by direct reading from the Infratec 1225 Grain Analyzer.

Analysis of data

Land equivalent ratio (LER), the relative land area required for single cropping to produce the same yield as the cropping system (Andrews and Kassam, 1976), was used to compare cropping systems. Using simple notation:

$$\mathrm{LER} = \frac{P_w}{M_w} + \frac{P_s}{M_s}$$

where P_w and P_s are the yields (kg ha^{-1}) of wheat and soyabeans respectively in single cropping, and M_w and M_s are their yields in the relay-cropping or double-cropping systems. Values of LER were calculated for each subplot and an analysis of variance was conducted on these data.

The economic analysis was based on estimates of the costs and returns of each cropping system. Detailed field records of material input applications were used to determine the costs of seed, fertilizer and herbicides using 1989 Arkansas prices. Charges for machinery and equipment variable inputs, labour, custom application and drying/hauling were estimated for each system, using Arkansas crop enterprise budgets (Clark *et al.*, 1990) and records of field operations were prepared for each treatment. Machinery ownership costs were charged against each budget by assessing a fixed ownership charge each time a piece of equipment was used.

The cost of wheat production was identical for relay cropping and double cropping. Production costs for soyabeans varied among cropping systems because of the different cultural practices used in single cropping, relay cropping, and double cropping. Soyabean production costs were added to the cost of wheat production to form the total specified cost of production for double- and relay-cropping systems.

Gross returns were computed by multiplying the plot yield of each crop component by crop price, the price being the five-year (1985–1989) average price received by farmers in Arkansas (Arkansas Agricultural Statistics Service, 1991), indexed to 1989 levels using the Consumer Price Index. Net returns, which excluded charges for land, management, risk, and general farm overheads, were calculated as the difference between gross returns and total specified costs of production for each treatment mean.

RESULTS AND DISCUSSION

Soyabean plant characteristics

The number of branches per soyabean plant was less in double cropping than in single cropping or relay cropping (Table 1), but the number of fertile nodes was the same for the three cropping systems. The height of soyabean plants was also greater in single cropping and relay cropping than in double cropping. Both the number of nodes and leaf area were significantly greater in single cropping than in either double cropping or relay cropping. In general these results agree with those reported in other studies (Carter and Boerma, 1979; Parker *et al.*, 1981) in which double-cropped soyabeans lodged less, had fewer branches and were shorter than single-cropped soyabeans.

High levels of lodging occurred in the relay-cropping system (data not shown)

Table 1. *Effect of single cropping, relay cropping and double cropping on selected characteristics of soyabeans at Fayetteville and Kibler in 1988–89 and 1989–90. (All values are means of blends and their constituent genotypes)*

Characteristic	Single cropping	Relay cropping	Double cropping	s.e.
Branch number	8.0	7.9	7.1	0.70
Node number	18.3	16.6	16.1	1.21
Plant height (cm)	86.3	85.2	74.6	0.19
Fertile node number	12.4	12.3	12.2	0.94
Leaf area (cm^2)	4091.0	3186.0	2671.0	1003.8

Table 2. *Selected characteristics of soyabean genotypes and blends, averaged across three cropping systems (single cropping, relay cropping and double cropping) two sites and two years*

Genotype or blend	Branch number	Node number	Fertile node number	Plant height (cm)	Leaf area (cm^2)
			Maturity Group V		
Shiloh	6.6	15.7	11.3	80	2980
R85-362	7.4	16.9	12.4	78	3257
Blend	7.4	16.5	12.4	79	3375
			Maturity Group VI		
B2-J	8.6	16.2	12.3	79	3256
R82-158	8.6	17.9	13.5	89	3693
Blend	7.9	18.7	12.2	85	3203
s.e.	0.40	0.65	0.54	2.0	244.6
Mean of genotypes	7.7	16.7	12.4	82	3296
s.e.	0.20	0.32	0.27	1.0	122.3
Mean of blends	7.7	17.6	12.3	82	3289
s.e.	0.28	0.46	0.38	1.4	173.0

as a consequence of the weak, etiolated stems. Palmer *et al.* (1990) also found that relay cropping increased lodging, but yield was not significantly reduced by relay cropping in either of these studies.

The Maturity Group V blend had the same leaf area, produced the same number of nodes and had the same plant height as the component genotypes (Table 2). The numbers of branches and fertile nodes of the blend were the same as those of the higher component, R85-362. In Group VI the blend produced the same number of fertile nodes and leaf area as the lower component, B2-J. For number of nodes and plant height the blend was equal to the higher component, R82-158. However, the number of branches for the blend was lower than for either of the components. Comparing the average of the four component genotypes and the average of the two blends there were no differences in any of the five plant traits. These results suggest that blends, in general, behaved similarly during vegetative growth to the average of the component genotypes.

Soyabean seed characteristics

In Group V, seed protein concentration was higher in single cropping, intermediate in relay cropping, and lowest in double cropping for both genotypes and the blend (Table 3). Under the cropping systems tested, the seed protein concentration of the blend was intermediate between the two component genotypes. The same trend was observed for the Group VI soyabean genotypes and the blend, where seeds were high in protein in single cropping, intermediate in relay cropping and low in double cropping. There was no difference between the blends and the average of their components averaged across Groups V and VI.

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Table 3. *Soyabean seed protein (g per kg fresh weight adjusted to 13% moisture) as affected by single cropping, relay cropping and double cropping at Fayetteville and Kibler in 1988–89 and 1989–90*

Genotype or blend	Single cropping	Relay cropping	Double cropping
		Maturity Group V	
Shiloh	382	367	352
R85-362	394	384	377
Blend	384	376	357
		Maturity Group VI	
B2-J	378	362	346
R82-158	381	371	361
Blend	381	368	358
s.e.	3.2		
Mean of genotypes	384	371	359
s.e.	1.6		
Mean of blends	383	372	358
s.e.	2.3		

In Group V there was little variation in seed oil concentration (data not shown). Within Group VI, seed oil was significantly higher for B2-J. The average of the two blends was no different in seed oil concentration than the average of the component genotypes. Single cropping produced soyabeans with the highest, relay cropping produced intermediate, and double cropping produced the lowest seed protein concentrations (Table 3). The inverse was observed for seed oil. In this case single cropping was the lowest, relay cropping intermediate and double cropping the highest in seed oil concentration. These results agreed with others (Hartwig, 1973; Wilcox, 1994) who reported an inverse relationship between protein and oil content in soyabean seed. Cartter and Hartwig (1962), however, reported a decrease in oil and a slight increase in protein concentration with a delay in sowing. This disagreed with the data that showed that later-planted double-cropped soyabeans were higher in oil concentration and lower in protein than the single crop.

Crop yields

The interaction between location and year significantly affected wheat yields. Cropping system also had a significant effect but there was no interaction between cropping system and location or year. Averaged across the two locations and two years, wheat yields (13% moisture) were 15% lower in the relay-cropping system (3306 kg ha^{-1}) than in the double-cropping system (3904 kg ha^{-1}). This yield reduction was probably due to mechanical damage to tillers when soyabeans were sown between wheat rows a month prior to harvest. Other researchers have found yield reductions of 15–34% in wheat, when soyabeans were relay cropped (Jeffers and Triplett, 1979; Reinbott *et al.*, 1987; Moomaw and Powell, 1990).

Table 4. *Soyabean seed yield (kg ha^{-1} adjusted to 13% moisture) as affected by single cropping, relay cropping and double cropping at Fayetteville and Kibler in 1988–89 and 1989–90*

Genotype or blend	Single cropping	Relay cropping	Double cropping
		Maturity Group V	
Shiloh	2013	1704	2173
R85-362	1663	1632	1975
Blend	1754	1889	2190
		Maturity Group VI	
B2-J	2242	2037	2183
R82-158	1995	1127	1487
Blend	1886	1442	1762
s.e.	135.7		
Mean of genotypes	1978	1625	1955
s.e.	67.8		
Mean of blends	1820	1666	1976
s.e.	95.9		

Soyabean yields were influenced by the interaction between genotypes, year and location as well as the interaction between genotypes and cropping systems. In Group V, the yield of the soyabean genotypes and the blend tended to be highest under double cropping, but only R85-362 gave significantly higher yields in double cropping than in either single or relay cropping (Table 4). In Group V the blend was similar to the average of the component genotypes in single cropping and double cropping but produced 221 kg ha^{-1} more than the average of the component genotypes in relay cropping. Previous reports have shown that blends out-yielded the average of their components (Schutz and Brim, 1967; Schweitzer *et al*., 1986), but it is not known why this trend was only seen under relay-cropping conditions. In Group VI no yield increase was observed for the blend when relay cropped and a statistical comparison of the average of the four component genotypes (Groups V and VI) with the average of the two blends indicated no difference in yield.

The yields of the Group VI soyabeans differed under the three cropping systems. There was a trend towards genotypes and blends yielding highest in single cropping, intermediate in double cropping and lowest in relay cropping. The average yield of the four genotypes was 17% lower in relay cropping compared with single cropping and double cropping, where yields were very similar. By comparison Jeffers and Triplett (1979) and Reinbott *et al*. (1987) reported a reduction in yield of relay-cropped soyabeans ranging from 16 to 43% compared with that of single-cropped soyabeans. The lack of superior yield in the single-cropped compared with the double-cropped soyabeans may have been due to the irrigation treatment since drought stress is one of the reasons why later-

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Table 5. *Land equivalent ratio (LER) of soyabean genotypes and blends grown with wheat in relay- and double-cropping systems at Fayetteville and Kibler in 1988–89 and 1989–90*

Genotype or blend	Relay cropping	Double cropping
	Maturity Group V	
Shiloh	1.64 g†	1.97 cde
R85-362	1.96 cde	2.32 a
Blend	1.77 efg	2.23 ab
	Maturity Group VI	
B2-J	1.83 efg	2.10 bcd
R82-158	1.79 efg	1.91 def
Blend	1.73 fg	2.17 abc
Mean of genotypes	1.80 c‡	2.07 b
Mean of blends	1.75 cd	2.18 a

†Means within a column followed by the same letter are not significantly different at the 0.05 probability level; ‡within columns, differences between genotypes or blends are not significant at the 0.05 probability level when followed by the same letter.

planted double-cropped soyabeans often have lower yields than single-cropped soyabeans. Furthermore, the constraints of our experimental design meant that the single-cropped soyabeans were grown under a no-till system. In the no-till area reduced yields may have been due to soil compaction which could have resulted in the small difference between single- and double-cropping systems.

Land equivalent ratio (LER) values allow a comparison of the productivity of the three cropping systems. An inherent assumption in the use of LER is that the yield of the monocrop represents ideal production (Mead, 1986). Within Group V soyabeans, the LER values of the blends and the component genotypes were higher in double cropping than in relay cropping (Table 5). The LER of the blends was no different from that of the average of the component genotypes. The same trend was observed for Group VI where the LER of double cropping was significantly higher than the LER of relay cropping, except for R82-158 which was the same for the two cropping systems. Averaging the four genotypes and the two blends showed that the LER of the blend was similar to the average of the component genotypes under relay cropping but that under double cropping the LER of the blends was higher. Agronomically, double cropping was more efficient in terms of yield than relay cropping, but both systems exceeded the single-crop efficiency as indicated by an LER > 1.

Economic analysis

Within Group V soyabeans, Shiloh showed a low net return as a single crop, an intermediate net return in relay cropping, and a high net return in double cropping (Table 6). The other cultivar, R85-362, and the blend, Shiloh/R85-362,

Table 6. *Net return ($ ha^{-1})† as affected by single cropping, relay cropping and double cropping at Fayetteville and Kibler in 1988–89 and 1989–90*

Genotype or blend	Single cropping	Relay cropping	Double cropping	Mean
		Maturity Group V		
Shiloh	130.49	274.45	414.09	272.93
R85-362	48.53	257.59	367.73	224.69
Blend	69.84	317.77	418.08	268.72
		Maturity Group VI		
B2-J	184.12	352.43	416.44	317.66
R82-158	126.28	139.33	253.45	212.05
Blend	100.75	213.10	317.85	210.64
s.e.	33.46			25.35
Mean of genotypes	122.30	255.95	363.05	256.78
s.e.	16.73			12.67
Mean of blends	85.30	265.55	367.96	239.68
s.e.	23.66			17.93

†Excludes charges for management, risk, land and general farm overheads.

followed the same pattern of profit distribution. In this maturity group, the highest net return was obtained from the blend in double cropping and the lowest return was from R85-362 in single cropping.

Group VI soyabeans followed a similar pattern. Except for the genotype, R82-158, which had a similar net return in relay and double cropping, component cultivars and the blend had low net returns in single cropping, intermediate returns in relay cropping, and high returns in double cropping. Within this group, the highest net return was from B2-J in double cropping and the lowest from the blend in single cropping. Blends and component cultivars had similar net returns under all cropping systems tested.

When compared across cropping systems, the Group VI cultivar B2-J gave the highest net return (US$318 ha^{-1}) followed by Shiloh in Maturity Group V (US$273 ha^{-1}). The lowest net returns were from the Group VI genotype, R82-158 (US$212 ha^{-1}) and the B2-J/R82-158 blend (US$211 ha^{-1}). The average of cropping systems demonstrated the same pattern of net return. Double cropping had the highest net return, relay cropping intermediate, and single cropping the lowest. These results were similar to those of Jeffers *et al*. (1973) and Sanford (1982) who found that double-cropping was more profitable than single cropping. However, the results were contrary to those of Graves *et al*. (1980) and Gogerty (1989) who found that soyabeans relay cropped into standing wheat produced average net returns higher than double-cropped soyabeans sown in wheat stubble. Although net returns in Table 6 were computed using five-year average prices for soyabeans and wheat, changes in the relative prices of the two crops would modify the estimated returns for each treatment (Mead, 1986).

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