FACTORS AFFECTING SELECTION OF DOUBLE-CROP SOYBEAN GENOTYPES

by

DEXTER EGGERS

B.S., Kansas State University, 1981

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1985

Approved by:

W.T. Schapaugh, Jr.
Major Professor

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Bill Schapaugh for his guidance and patience during the duration of this study. Appreciation is also extended to Drs. Stan Ehler and Dallas Johnson for their help and guidance during my work at Kansas State.

Gratitude is extended to fellow graduate students and workers on the soybean crew who made the "magnitude of our sacrifice" much more bearable, through their bad jokes and good humor.

Finally, I would like to thank my parents, John and Yvonne, for their support and understanding through all of this.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES cont.

CHAPTER I.

GENOTYPE X PRODUCTION SYSTEM INTERACTIONS, AND THE IMPORTANCE OF PHYTOTOXIC SUBSTANCES FROM WHEAT STRAW, IN DOUBLE-CROP SOYBEAN CULTIVAR DEVELOPMENT

ABSTRACT

Twenty-five randomly chosen determinate and indeterminate soybean [*Glycine max* (L.) Merr.] lines of early group V maturity were grown in two tillage treatments (wheat straw vs. fallow) over two years (1982, 1983) to determine the influence of wheat residue and stem termination on soybean double-crop performance and to assess the magitude of genotype x production system interactions in double-crop cultivar development.

Seed yield was significantly lower in wheat residue environments (1820 Kg/ha) than fallow environments (1930 Kg/ha). Indeterminate lines outyielded determinate lines by 11%. Indeterminates showed only a 1% reduction in yield in wheat residue environments, while determinates suffered a 9% reduction.

Genotypic variation for seed yield was masked by significant genotype x tillage treatment and genotye x environment interactions. The magnitude of the genotype x tillage treatment interaction indicated that the development of double-crop cultivars would be expedited by the testing and selection of lines in wheat residue environments.

Cold water extracts derived from wheat straw stimulated soybean seedling growth when applied to pots in the greenhouse. Seedling growth and percent nitrogen were substantially reduced, however, when seedlings were grown in pots mixed with wheat straw. Therefore, nitrogen availability is probably a more important factor limiting the growth of soybeans in soybean double-crop production than the phytotoxicity of compounds leached from wheat straw.

A greenhouse evaluation was not effective in identifying lines tolerant to the effects of wheat straw. Dry matter production, plant height, and percent nitrogen of seedlings were significantly reduced (13, 41, and 46%, respectively) among 25 lines evaluated. While the relative reduction for these traits differed among lines, plant responses in the greenhouse were not correlated to performance in the field.

Additional index words: Growth habit, stem termination, residue management, nitrogen immobilization, plant breeding, genetic improvement, tolerance, *Glycine max*, plant traits.

INTRODUCTION

Limiting factors of paramount importance in wheat-soybean double-crop systems are length of growing season and availability of soil moisture. Methods of residue management can affect both of these factors. The use of minimum tillage or zero-till systems extend the growing season by allowing the planting of soybeans immediately following wheat harvest, whereas more extensive methods, such as plowing or heavy disking require additional seedbed preparation. By leaving a straw mulch on the surface, minimum tillage methods increase water conservation and reduce soil erosion (22,28). The removal of wheat residue by burning allows the early planting of soybeans, but ignores the benefits of a mulch. In addition, the practice of burning crop residues may be legislated out of existence in the future, particularly near population centers (20).

Although the use of minimum tillage systems offer benefits in the production of double-crop soybeans they are not without drawbacks. A deleterious effect on growth and yield of soybeans in these environments may be a result of wheatstaw *per se*.

Caviness (6) related how researchers and farmers in the southern U.S. have noticed reduced growth of soybean seedlings in double-crop environments. He explained how this inhibition can reduce yields, and may be a result of phytotoxic activity associated with the presence of wheat straw.

Phytotoxic activity may be a result of 1) initial leachates from undecomposed straw (15,16), 2) substances released from wheat straw during decomposition (17,18), 3) toxins produced by microorganisms during the decomposition of wheat straw (7), and 4) the immobilization of inorganic nitrogen by soil microflora (1).

Elliot et al. (10) reviewed work done on the phytotoxicity associated with crop residues. They listed a number of phytotoxic compounds which have been isolated from fresh and decomposing crop residues by various workers, which included a wide array of simple and complex compounds. The type and quantity of compounds released from wheat straw were presumed to depend upon their water-solubility and the type of microflora which develop.

While all the described effects of wheat toxcity may influence soybean seedling growth in wheat-soybean double-crop systems, their relative importance remains undetermined. Selection of lines tolerant to all effects would drain available resources and severely limit genetic improvement. However, if one factor can be identified which exhibits the greatest impedance to growth, then breeding energies could be directed to improve that trait and greater genetic gain would be realized.

The development of soybean lines tolerant to the effects of wheat straw may improve yields in double-crop environments and would animate the use of minmimum tillage systems, with additional yield advantages obtained through improved cultural practices.

Double-crop cultivar development would be expedited by the selection and testing of lines in environments specific to this production system. The need for such a breeding scheme, however, would depend upon whether or not significant genotype x production system interactions occur. If these interactions occur, it would indicate that different factors may be responsible for yield in double-crop environments.

In addition to possible phytotoxic associations, crop residues are known to affect plant growth by influencing soil physical, soil chemical properties, and the crop microclimate (26). It could be assumed that previous wheat crop growth, independent of residue effects, would also influence soil physical and chemical properties and affect subsequent double-crop development. Therefore any differential response amoung soybean lines grown in the fallow and wheat residue environments may be due to effects of crop residues, independent of phytotoxcity; effects of previous plant growth, including possible allelopathic effects; or tolerance to wheat straw phytotoxicity.

One way to improve double-crop cultivars adapted to southeastern Kansas may be through the use of indeterminate stem growth. Currently, the best adapted cultivars to southeastern Kansas are early maturity group V (MGV) determinates. Indeterminate stem growth differs from determinate stem growth in that indeterminates continue growth in stem length and leaf production after flowering, while determinates terminate stem growth when flowering begins (3). This difference in growth may give indeterminates an advantage in adverse conditions because they flower over a longer period, possess more nodes, and allow deeper light penetration into the crop canopy (12). Plant height, number of reproductive nodes, and length of reproductive period are traits which are positively related to seed yield and may have a stronger relationship with yield in late environments (4,5). In addition, indeterminate genotypes have been reported to out yield and be more yield stable than determinate genotypes in northern soybeans (2,27). It might be predicted, therefore, that tall, indeterminate, MG V genotypes would enhance the soybean yields in the double-crop production systems of southeastern Kansas.

Cox (9) found a differential seed yield response among soybean cultivars grown in a double-crop and winter-fallow environment when planted on the same date. In the greenhouse these cultivars also showed differential responses in dry matter production of seedlings when grown in pots containing 2% wheat straw (w/w) and in pots containing only soil. Cultivars exhibited similar responses in the field and in the greenhouse. These results indicate that 1) selection of soybeans tolerant to the toxic effects of wheat straw may be possible and 2) a greenhouse selection technique for tolerant lines might be developed. This work did not differentiate effects of N immobilization from effects of wheat straw toxicity.

Some cultivars of wheat straw appear to be more toxic to seedling growth than others (17,18), and high straw concentrations may have a greater inhibitory effect than lower concentrations (9). Implications are that the selection of a wheat cultivar to precede soybeans may influence the success of double-crop production.

The purpose of this research was to: 1) compare the growth and yield of soybean lines in a wheat residue environment previously cropped to wheat, and in a fallow environment free of previous crop effects, 2) assess the magnitude of genotype x production system interactions in double-crop soybean cultivar development, 3) determine the influence of stem termination type on soybean seed yield in double-crop environments, 4) evaluate the importance of phytotoxic substances leached from wheat straw in the stunting of soybean seedlings, and 5) evaluate a greenhouse technique for screening lines tolerant to the effects of wheat straw.

MATERIALS AND METHODS

I. Field Experiments

Field experiments were conducted in southeastern Kansas at the Columbus Experimental Field near Columbus, Kansas in 1982, and on a farm near Pittsburg, Kansas in 1983. The soybean plots were planted in a Bates silt loam (Typic Argiudolls, fine-loamy, siliceous, thermic) in 1982, and in a Parsons silt loam (Mollic Albaqualfs, fine, mixed, thermic) in 1983.

The experimental design was a split-plot with tillage treatments as whole plots and soybean genotypes as sub-plots. The subplot treatments were arranged in a 5 X 5 balanced lattice square design, with three replicates. Genotypes consisted of 11 randomly chosen determinate lines and 11 randomly chosen indeterminate lines from F_5 progeny rows, and three check varieties: 'Essex', 'Forrest', and K77-46-62. The lines chosen, from four different crosses, were no earlier, and no more than three days latter in maturity than Essex. Tillage treatments included soybeans grown in a wheat residue environment and a fallow environment. The fallow treatment was achieved by killing blocks of wheat in a growing field, with .84 Kg/ha active ingredient glyphosate in early April, before substantial growth had occurred. Wheat was harvested from the residue treatment in a conventional manner, using a self-propelled combine. Both tillage treatments were disked heavily prior to planting. Planting dates for both treat ments were 2 July 1982, and 8 July 1983. Beans were harvested 4 Nov. 1982 and 20 Dec. 1983. A very wet fall delayed harvest in 1983.

In 1983, soil in each tillage treatment was sampled to a depth of 15 cm. Fertility levels of N and P were measured. Percent soil moisture was also determined gravimetrically.

The plots consisted of four rows 76 cm apart and 6.1 m long. Plots were end-trimmed at maturity to 4.6 m and the center two rows were machine harvested. Seeds were planted at 26/m in both environments. Weed control was achieved with 4.6 Kg/ha active ingredient alacholor applied at planting, and plots were kept clean by hand weeding. In 1982, approximately 0.2 Kg/ha active ingredient acifluoren was applied three weeks after planting to control a late weed problem.

In general, rainfall was less than normal for both years. In 1982, rainfall was near normal in Aug., during the late vegetative and early flowering period, but averaged 9 cm below normal in Sept. and Oct., during pod-fill and maturity. In 1983, rainfall averaged 7 cm below normal during Aug. and Sept., while Oct. rainfall was 16 cm above normal. Temperatures were near normal during July and Aug. of 1982, while Sept. and Oct. averaged .4 C cooler than normal. July, Sept., and Oct. of 1983 averaged .4 C warmer than normal, while Aug. was 3.2 C warmer than normal.

Plant traits measured in 1982 were seed yield and mature plant height. In 1983, additional measurments included 100 seed weight and percent leaf nitrogen. Plant height was measured at maturity. Seed weight was recorded from 100 random seeds sampled after harvest. Percent leaf nitrogen was determined by sulfuric-peroxide digest, as described by Lowther (19) in a Technicon Auto-Analyzer II. Leaves were sampled from the third trifoliate of seedlings in the V4 (11) stage of growth.

In the analyses of variance, years and genotypes were considered random effects and tillage treatments were fixed. Adjusted means for genotypes in the sub-plots were obtained by lattice square analysis, as described by Cochran and Cox (8), and were included in the split-plot analysis and combined over years.

II. Greenhouse Studies.

Greenhouse studies were conducted in July and September of 1983 and January of 1984 to assess the effect of wheat straw on the early stunting of soybean seedling growth and to determine the relative importance of nitrogen immobilization and the release of phytotoxic substances from wheat straw. Six plants were planted in 2 liter pots and thinned to three plants upon emergence. The potting medium consisted of one part fine sand and one part silt loam soil. The soil used had not been cropped for several years and contained no plant residues. No rhizobium bacteria were applied to pots and little nodulation was noted.

Wheat straw was prepared by grinding in a hammer mill to pass through a 32 mm screen. Sources of wheat straw were from field plots grown in conjunction with this study and from Kansas State University foundation seed plots. Residue was collected and ground immediately following wheat harvest and stored at 10 C until used.

Supplemental greenhouse lighting was provided by Sylvania 1000 watt, high-pressure sodium, Maxi-Grow Batwing lamps. Greenhouse temperatures were maintained near 21 C nighttime and 27 C daytime. Treatment combinations were replicated four times and arranged in a randomized complete block design.

The following information provides a specific description for each test.

Cold Water Extract and Nitogen Fertility Levels. Three check lines; K77-46-62, Essex, and Forrest were grown in factorial combinations with three nitrogen fertility levels and three concentrations of cold water extracts from wheat straw. The three fertility levels were achieved by amending soil-sand mixtures to 10 ppm, 20 ppm, and 40 ppm nitrogen, with ammonium nitrate. These concentrations correspond to low, medium, and very high fertility levels for soybeans grown in Kansas.

To obtain cold water extracts, ground wheat straw of the cultivar Newton was intermitently stirred in a cement mixer with distilled water for three hours, at 25 C , in a ratio of 10:1 (water/straw). Residue was filtered out of the mixture by pouring though 10 layers of cheese cloth. Extracts were immediately stored at 5 C. Electo-conductivity of extract solutions was less than 2 millimhos/cm.

The concentrations of extract used were: 100% extract, 50% extract-50% distilled water, and 100% distilled water. Fifty ml of the appropriate concentration of extract was applied to pots every other day for the first week and 100 ml was applied every other day, thereafter. Supplemental distilled water was applied as needed. Enough cold water extract was made at a set to supply pots for two treatments. Planting was in late January and plants were grown under a 15 hour photoperiod with supplemental lighting. At harvest (V4 stage of development), average plant height and total dry weight per pot were measured.

Greenhouse Evaluation. Twenty-five soybean lines were grown in pots containing 0 and 2% wheat straw (w/w), of the cultivar 'Newton'. The soybean lines consisted of 11 determinate and 11 indeterminate lines randomly chosen from F_5 progeny rows which had not been subjected to previous selection pressure. Three check lines; Essex, Forrest, and K77-46-62 were also included. These were the same lines grown in field studies in conjuncton with this test. Genotypes were considered a random effect in the analyses of variance.

Seeds were planted in early September and supplemental lighting was provided for two hours in the early morning. Average plant height (cm) and total dry weight per plot (g) were measured following the V4 (11) stage of development. Dried samples were ground in a Wiley mill to pass a 2 mm screen. Percent total nitogen per sample was determined by sulfuric-peroxide digestion as described by Lowther (19), in a Technicon Auto-Analyzer II.

Wheat Cultivar and Straw Concentration. Ground straw from three cultivars of wheat commonly grown in southeastern Kansas were thoroughly mixed, by hand, with the soil at concentrations of 0, 0.5, 1.5, and 3% (w/w). These concentrations, except for the control, correspond to to field residue concentrations expected from a wheat crop yielding 3360 Kg/ha (50 bu/A), incorporated to depths of 7.62 cm, 2.54 cm, and 1.27 cm, respectively. Wheat cultivars used were 'McNair' (a soft red winter wheat), 'Newton', and 'Tam 105'.

Three soybean lines used in the test were 'Essex', 'Forrest', and K77-46-42. These lines were checks used in field studies conducted in conjuntion with this experiment. Seeds were planted in early July and two hours of supplemental lighting was provided in the early morning.

Average plant height (cm) per pot was taken after four weeks, following the V4 (11) stage of development. Plants were clipped at the soil surface and dried at 34 C for three days. After drying, total plant dry weight per pot was measured.

RESULTS AND DISCUSSION

Field experiments. Tillage treatments influenced soybean growth and yield (Table 1). Seed yield and 100 seed weight were significantly reduced in wheat residue environments; with plant height and seedling leaf nitrogen tending to be lower in these treatments. The effects of wheat residue environments on plant height and seedling leaf nitrogen were masked by significant tillage treatment x location interactions.

Plant height was significantly taller in the fallow environment (88 cm) than the residue environment (76 cm) in 1982; however, there was little difference in height between the two tillage treatments in 1983 (54 cm, fallow; 53cm, residue). This differential response for plant height may be due to climatic differences in the two years. Although beans were stressed during both years, stress periods came at different times. In 1983, major stress occurred during vegetative growth and plant height was not well expressed; while in 1982 major stress occurred after flowering, not during vegetative growth, allowing differences in plant height due to tillage treatments to be displayed.

Percent seedling leaf nitrogen was significantly greater in the fallow treatment (5.10 %) than the residue treatment (4.74 %) at the Pittsburg location; but was lower, although not significantly, at the Parsons location (4.69 %, fallow; 4.83 %, residue). This interaction may be explained due to different soil fertility levels in the tillage treatments at the time of planting.

Soil fertility tests taken before planting indicated that N

Table 1. Effect of tillage treatment and stem termination type on several plant traits.

Effect	Plant traits†			
	Seed yield	Plant height	Seed weight	Leaf nitrogen
	Kg/ha	cm	g/100 seed	%
Treatment				
Fallow	1930 a	71 a	15.6 a	4.89 a
Residue	1820 b	64 a	15.1 b	4.77 a
Termination type				
Determinates	1774 b	59 b	15.5 a	4.82 a
Indeterminates	1963 a	78 a	15.6 a	4.85 a

† Means followed by the same letter within a column and effect are not statistically different at the 0.05 level of probability.

levels were nearly the same in both tillage treatments at the Parsons location, but were lower in the wheat residue environment at the Pittsburg location. This difference in available N could account for the tillage treatment x location interaction for leaf nitrogen. Seedling nodulation at both locations, however, was observed to be much greater in the wheat residue environments, indicating that N was severely limited in both wheat residue environments (24).

Seed yields in the residue treatments were reduced by 5%, in 1982, and 7% in 1983. Although significant, these reductions where not drastic in the low yield potential environments where the soybeans were grown. Lower yields in the wheat residue are probably more a result of soil physical and soil chemical conditions than phytotoxicty associated with wheat straw.

At planting, residue treatments were wetter than fallow treatments. Soil moisture averaged 16% in the residue treatments and 14% moisture in the fallow treatments. Therefore, although both treatments were disked prior to planting, soil compaction occurred in the wheat residue treatments, but not the fallow treatments. The effects of soil compaction were witnessed by twisted and contorted growth of seedling root systems in the wheat residue treatments compared with the fallow treatments.

In addition to compaction problems, stand establishment was reduced in the wheat residue treatments in 1983, probably as a result of poor soil-seed contact. Stand establishment averaged 88% in the fallow treatments and only 50% in the residue treatments in 1983. Stand establishment was considered adequate for both treatments in 1982.

Soil fertility tests also indicated that N and P levels tended to be lower in the residue environments than the fallow environments, prior to planting. As was previously mentioned, N was probably severely limiting during soybean seedling growth in the wheat residue regimes. This is likely a result of the immobilization of inorganic N by microflora during the decomposition of wheat straw (1). Therefore, the problems associated with soil compaction, stand establishment, and available nutrients could account for the moderate yield reductions in the wheat residue treatments; and phytotoxicity which has been associated with wheat straw probably was not a major factor in these yield reductions.

Indeterminate lines outyielded determinate lines by an average of 11% (Table 1). Indeterminates were also taller than determinate lines. No significant stem termination type x treatment or location interactions occurred for any trait.

Higher yields for indeterminate lines was attributed to greater seed weight in a previous report (12). In this study, however, there was little difference in seed weight between stem termination types (Table 1).

Maturity data indicated that indeterminates averaged 3 days later than determinates, which could give indeterminates a yield advantage in these late-planted environments. However, average maturity and overall mean seed yield were not well correlated (r=.11).

Genotypic variation was not significant in the analysis of variance for seed yield or leaf nitrogen (Table 2), but was for

Table 2. Estimates of genetic and interaction components of variance and their standard error for three plant traits.

Effect	Plant traits		
	Seed yield	Plant height	Leaf nitrogen
Genotype (Gen)	3918±5219	108.7±31.7**	.0035±.0033
Gen x Location (Loc)	8008±4946*	5.9± 3.1**	-.0002±.0031
Gen x Treatment (Trt)	9346±5280*	.6± 1.9	.0003±.0038
Gen x Loc x Trt	257±6188	-1.1± 2.0	.0007±.0061

*,** Significant at the .05 and .01 levels, respectively.

plant height. Genotypic variation for seed yield was masked by significant genotype x tillage treatment and genotype x location interactions. A significant genotype x location interaction occurred for plant height.

Genotype x environment interaction in soybean breeding trials limits the effective selection of superior lines. This is particulary true in Kansas, where large fluctuations in climatic conditions contribute to these interactions. Soybeans are selected over a number of environments and years to control these relatively large interactions. It was therefore suprising to find that, for seed yield, the magnitude of the genotype x tillage treatment interaction component of variance was as large as the genotype x location component (Table 2).

The magnitude of the genotype x tillage treatment interaction indicates that different factors may be responsible for yield under double-crop conditions and that the development of double-crop cultivars would be expedited by the testing and selection of lines in wheat residue environments.

As was mentioned previously, climatic conditions between the two years had a drastic effect upon the expression of plant height. Genetic differences in plant height were better displayed in 1982 than 1983, which contributed to the genotype x location interaction for this trait. The interaction component of variance, however, was still much lower than the genotypic component (Table 2). It might also be noted that the test of significance for this interaction was very sensitive, as the R-square value for the model in the analysis of variance was .98.

Seed yield and plant height averaged 13% and 34% lower, repectively, at the Pittsburg location than the Columbus location. All plant height means and all but two yield means for genotypes were lower in the Pittsburg environment. Therefore, the nature of the genotype x location interactions for these two plant traits depended upon the degree which growth and yield was reduced among lines between the two locations. Several substantial changes in rankings occurred among lines for seed yield at the two locations (Table 3), but changes in ranks were not as substantial for plant height.

The yield differential between stem termination types was greatest under more adverse conditions. Mean seed yields in the Columbus-fallow, Columbus-residue, Pittsburg-fallow, and Pittsburg-residue environments were 2057, 1963, 1803, and 1637 Kg/ha, respectively. The indeterminate lines outyielded determinate lines by 1%, 12%, 12%, and 19% in these environments, respectively. Averaged over locations, indeterminates showed only a 1% reduction in yield from the fallow environments to the wheat residue environments, while determinates suffered a 9% reduction (Table 3). Indeterminate lines may, therefore, be more yield stable than determinate lines in late-planted double-crop situations.

Another aspect of the comparison between the stem termination types is the ranking of means. In the residue environmnents, seven out of the top eight lines were indeterminates (Table 3). The ranking of line means over all environments showed that the top nine lines were all indeterminates, which included the indeterminate check (K77-46-62). The randomly chosen indeterminate

Table 3. Line means and rankings in two tillage treatments and at two locations for seed yield.

Genotypes within Groups	Tillage treatments				Locations			
	Fallow		Residue		Columbus		Pittsburg	
	Kg/ha	rank	Kg/ha	rank	Kg/ha	rank	Kg/ha	rank
Checks								
Essex	2066†	1	1703	20	2050	10	1720	17
Forrest	1989	9	1798	17	1962	18	1825	9
K77-46-62	1835	21	1851	13	2117	6	1882	4
Mean	1963 ab		1784 ab		2044 ab		1809 b	
Determinates								
K77-46-23	1929	12	1643	21	2009	12	1562	22
K77-46-45	1996	8	1314	25	1975	16	1334	25
K77-46-78	1882	17	1505	23	1949	20	1438	23
K77-50-09	1700	24	1391	24	1710	25	1381	24
K77-50-33	1804	23	1818	16	1865	21	1737	15
K77-50-59	1868	18	2009	4	2261	1	1616	20
K77-63-44	1861	19	1878	10	1976	15	1764	13
K77-63-67	1835	21	1730	19	1845	22	1720	17
K77-63-76	1697	25	1670	22	1777	24	1589	21
K77-66-03	1956	11	1892	9	2003	14	1845	7
K77-66-32	1912	14	1737	18	1969	17	1680	19
Mean	1858 b		1690 b		1942 b		1606 c	
Indeterminates								
K77-46-19	1915	13	1841	15	1956	19	1801	10
K77-46-40	2066	1	1875	11	2093	8	1848	6
K77-46-42	1835	21	1851	13	1841	23	1844	8
K77-53-53	2029	4	2110	1	2033	11	2107	1
K77-50-63	1989	9	1915	8	2154	4	1751	14
K77-50-73	2026	5	2013	3	2157	3	1882	4
K77-63-52	2003	7	1979	6	2184	2	1798	11
K77-63-84	1912	14	1935	7	2073	9	1774	12
K77-63-87	2019	6	1865	12	2130	5	1734	16
K77-66-42	2040	3	1982	5	2113	7	1908	3
K77-66-50	1898	16	2070	2	2009	12	1959	2
Mean	1976 a		1949 a		2070 a		1855 a	
LSD(.05)	204		338		370		280	

† Group means followed by the same letter within a column are not statistically different at the .05 level of probability.

lines even outyielded the checks at both locations and in both tillage treatments (Table 3). This is most suprising since the checks represent well adapted lines which have been selected for yield potential in many environmnents, while the random lines had not been subjected to any previous selection pressure for yield.

The use of indeterminate stem growth should improve cultivars adapted to southeastern Kansas and its double-cropping production system. This could be accomplished by the testing and selection of indeterminate lines, or by incorporating indeterminate stem growth, though backcrossing, into currently adapted cultivars, as this trait is controlled by a single gene (3).

Greenhouse experiments. Table 4 depicts the mean effects of three soybean genotypes, three nitrogen fertility levels, and three concentrations of cold water extracts derived from wheat straw on soybean seedling dry matter production and plant height. No significant two-way or three-way interactions occurred between main effects for either trait.

'Forrest' seedlings were significantly taller than 'Essex' and K77-46-62 seedlings, while K77-46-62 seedlings exhibited significantly greater dry matter production. These relationships among the genotypes were consistent throughout the study, and are interesting to note because K77-46-62 demonstates indeterminate stem termination, while Essex and Forrest are determinates.

Nitrogen fertility levels did not significantly effect dry matter production in seedlings. N levels were significant (p=.045) for height, but means were not clearly separated. Evi-

Table 4. Mean effects of three nitrogen fertility levels, three concentrations of cold water extracts derived from wheat straw, and three genotypes on soybean seedling growth.

Effect and level	Plant traits†	
	Seedling height	Dry weight
	--cm--	g/pot
Genotype		
Essex	14.5 b	2.25 b
Forrest	17.0 a	2.28 b
K77-46-62	14.4 b	2.56 a
Nitrogen levels		
10 ppm	15.3 ab	2.36 a
20 ppm	14.9 b	2.31 a
40 ppm	15.6 a	2.43 a
Extract Concentration		
100% water	14.8 b	2.05 b
1:1 water/extract	15.4 a	2.52 a
100% extract	15.6 a	2.52 a

† Means followed by same letter within a column and effect are not statistically different, according to LSD proceedure (p=.05). Means are averages of 36 observations.

dently, all fertility levels used provided ample nutrition for seedling growth in the greenhouse. Dry weight and seedling height were lowest in the medium level of fertility (20 ppm) and the very high level (40 ppm) had the highest means for both traits. Cold water extracts derived from wheatstraw stimulated growth of soybean seedlings, as plant height and dry matter production were significantly greater when the extracts were used. These results are in contrast to those of other workers who demonstrated reduced root and shoot elongation of various crop seedlings when grown in cold water extracts derived from undecomposed wheat straw (9,13,16,17).

Most workers agree that the release of toxic compounds is greatest during early decomposition (10,16,17), and some report that initial toxicity from undecomposed straw is minimal or nonexistent (7,10,21). The results of this study agree with the latter group. The stimulatory effect observed could be explained by possible interactions of toxic compounds, leached from straw, with the soil, or the effects of leached nutrients on plant growth.

Schneider and Wightman (23) reviewed work concerning the effects of various compounds on indoleacetic acid (IAA) oxidase activity. They report that monophenols reduce stem elongation by acting as coenzymes for IAA oxidase, while diphenols, polyphenols, and auxin protectors (complex polymers containing phenolic compounds), are inhibitors of IAA oxidase and sometimes produce stimulatory effects when applied to plant parts. Monophenols and diphenols are often identified in extracts derived from wheat straw (9,10,15).

Much work indicates that soil inactivates or adsorbs phytotoxic compounds (10,14,21). Guenzi and McCalla (14) indicated that the bulk of the monophenolics they identified in soil where combined to organic constituents by ester linkages. The soil may, therefore, provide a possible sieving action for phenolic compounds , 'trapping' monophenols and allowing diphenols and auxin protectors greater availability to plants, which could stimlulate growth.

In addition to possible stimulation of plant growth through inhibition of IAA oxidase by compounds contained in the extract, stimulation of plant growth could result from soluble nutrients supplied by the leachate (25).

More research is needed to fully assess the impact of leachates derived from wheatstraw on plant growth. More substances, including compounds and complex polymers, which may affect plant growth need to be indentified. The interactions of these compounds with the soil, the concentrations required to affect plant growth, and the biochemical nature of these compounds in plant systems also needs to be investigated.

It is evident from this study that leachates derived from undecomposed wheat straw do not reduce soybean seedling growth when allowed to interact with the soil. These results do not discount possible localized effects of leachates when straw is in close proximity to plant parts or the effects of toxins produced during decomposition of wheat straw.

Two percent wheatstraw mixed with soil significantly reduced the average height, dry weight and percent nitrogen of soybean seedlings by 13, 41, and 46%, respectively (Table 5). Determinate seedlings were significantly taller than indeterminate seedlings, but determinates did not exhibit significantly greater dry matter production. There was no difference in percent tissue nitrogen between stem termination types. A significant stem termination type x treatment interaction occurred for seedling height and was due to indeterminates suffering less reduction in seedling height (10%) than determinates (17%).

Analyses of variance indicated that genotypes were significant for seedling height and dry weight, but not percent nitrogen. Significant genotype x treatment interactions occurred for all three plant traits. Genotypic means and their rankings for each trait in each treatment are shown in Table 5. Substantial changes in the ranking of genotypic means between the the two treatments occurred for all three traits, particularly for percent leaf nitrogen.

The LSD values were high relative to the range of means found for percent leaf nitogen. It was noted that the statisical model in the analyis of variance accounted for only 52% of variabliy in the experiment for this trait, as compared with 87 and 81% for dry weight and seedling height, respectively. The relatively large error for leaf nitogen can not be attributed to the procedure used to measure this trait, as this proceedure has a SD= +/- .01%. Evidentally, nitrogen fertility within pots varied widely even though the same soil was used.

Correlations between control means and straw treatment means (Table 6) indicate that genotypes were most variable in their response to treatments for percent leaf N, and least variable for

Table 5. Effects of 2% wheat straw (w/w) mixed with soil on soybean seedling growth for twenty-five genotypes.

Genotypes and Groups	Seedling height				Dry weight				Leaf nitrogen			
	Control		Straw		Control		Straw		Control		Straw	
	cm	rank	cm	rank	g/pot	rank	g/pot	rank	%	rank	%	rank
Checks												
Essex	8.4[†]	10	7.2	16	1.90	23	1.11	21	2.10	6	1.52	21
Forrest	11.7	1	8.6	2	2.06	15	1.23	13	1.96	21	1.48	24
K77-46-62	8.2	12	7.7	8	2.17	11	1.37	5	2.20	2	1.69	15
Mean	9.4 a		7.8 a		2.04 a		1.24 a		2.09 a		1.56 b	
Determinates												
K77-46-23	9.7	3	8.3	3	2.33	5	1.33	7	2.07	12	1.91	4
K77-46-45	9.6	4	8.0	5	2.25	6	1.58	1	2.05	14	1.49	23
K77-46-78	7.8	18	7.4	12	2.00	18	1.28	10	2.09	8	1.75	12
K77-50-09	7.6	20	6.5	23	1.68	25	1.14	18	2.36	1	1.50	22
K77-50-33	8.1	13	6.4	24	2.15	13	1.10	22	1.97	20	1.72	14
K77-50-59	9.0	7	7.8	7	2.25	16	1.27	9	1.92	23	1.98	1
K77-63-44	8.1	13	7.6	10	1.80	24	1.10	22	2.01	18	1.93	2
K77-63-67	11.2	2	9.3	1	1.99	19	1.09	24	1.96	21	1.60	18
K77-63-76	8.8	9	7.3	14	2.43	2	1.21	15	1.91	24	1.75	12
K77-66-03	9.5	5	7.3	14	2.36	3	1.43	3	1.91	24	1.93	3
K77-66-32	8.3	11	7.9	6	2.59	1	1.46	2	2.06	13	1.88	6
Mean	8.9 a		7.6 a		2.17 a		1.27 a		2.03 a		1.77 a	
Indeterminates												
K77-46-19	8.0	15	7.2	16	2.18	10	1.32	6	2.02	17	1.80	9
K77-46-40	7.3	24	7.0	19	1.96	21	1.23	13	2.08	10	1.79	10
K77-46-42	7.4	23	6.1	25	2.01	17	1.38	4	2.08	10	1.55	20
K77-50-53	7.7	19	7.6	10	1.88	23	1.32	6	2.18	3	1.64	17
K77-50-63	7.3	24	7.1	18	1.98	20	1.18	16	2.09	8	1.60	18
K77-50-73	8.0	15	7.7	8	2.04	16	1.37	5	2.09	8	1.81	8
K77-63-52	9.1	6	8.1	4	2.19	9	1.14	18	1.98	19	1.88	6
K77-63-84	7.5	21	6.8	21	2.16	12	1.13	20	2.18	3	1.42	25
K77-63-87	8.9	8	7.4	12	2.22	8	1.05	25	2.05	14	1.76	11
K77-66-42	7.5	21	6.6	22	2.36	3	1.27	11	2.04	16	1.67	16
K77-66-50	7.9	17	6.8	20	2.12	14	1.15	17	2.12	5	1.89	5
Mean	7.9 b		7.1 a		2.10 a		1.23 a		2.08 a		1.71 a	
LSD(.05)	.9		.9		.30		.30		.30		.30	

[†] Means followed by the same letter within a column are not statistically different at the 0.05 probability level.

seedling height, and that indeterminates varied more than determinates in response to wheatstraw, especially for dry matter production.

The relative performance of a genotype was calculated as a percentage of the control mean when it was grown in the straw environment. Genotypes which showed less reduction for one trait generally did not exhibit 'tolerance' for another trait. An exception was K77-50-53, which showed the greatest relative performance for dry weight, and also ranked second for seedling height.

Correlations among plant trait means for the relative performance of genotypes are shown in Table 6. The main comparison noted here was a moderate positive correlation between dry weight and seedling height for indeterminates, while there was a moderate negative correlation between dry weight and percent nitrogen for determinates.

Correlations between seedling height, dry weight, and percent N are given in Table 7. Correlations are presented overall, by treatment and by stem termination type. In general, responses were not well correlated among traits. Dry weight (DWT) and seedling height (HT) were always positively correlated, and were correlated stronger overall, than in either treatment. The stronger overall correlation between these two traits is due to the determinates being taller but not exhibiting greater dry matter production. Indeterminates had a stronger correlation between DWT and HT in the control treatment, than when grown in 2% straw. Overall, DWT was positively correlated with tissue nitrogen (N).

Table 6. Correlations between control means and means when genotypes were grown in 2% wheatstraw for three plant traits and correlations between traits for the relative performance of genotypes.

Comparison	Group		
	Overall	Determinates	Indeterminates
Control v. straw			
Height (HT)	.88***	.82***	.68**
Dry weight (DWT)	.43**	.67*	-.29
Percent nitogen (N)	-.42**	-.41	-.50*
REL PRF			
DWT/HT	.31	.19	.50*
DWT/N	-.37*	-.50*	-.25
HT/N	-.05	.13	.16

*,**,*** Significant at the .10, .05, and the .01 levels, respectively. REL PRF=relative performance, calulated as a percentage of the control mean when a genotype was grown in the straw treatment.

Table 7. Simple correlations between seedling height (HT), dry weight (DWT), and percent nitrogen (N), overall, by treatment, and by stem termination type.

Classification	DWT/HT	DWT/N	HT/N	n
Overall	.51**	.33**	.16*	200
Determinates	.56**	.30**	.15*	104
Indeterminates	.52**	.36**	.27**	96
No straw	.29**	-.59**	-.32**	100
Determinates	.26**	-.54**	-.31*	52
Indeterminates	.41**	-.67**	-.28	48
2% straw	.25**	0	.12	100
Determinates	.30*	.12	.03	52
Indeterminates	.20	.16	.25	48

*,** Significant at the .05 and .01 levels, respectively. Number of observations.

In the control treatment, however, strong negative correlations occurred, while in the straw treatment there were no significant correlations between DWT and N. Correlations between HT and N were similar to those between DWT and N, however they were not as strong.

It was noted that K77-50-53, which had a high relative performance for two traits in the greenhouse, also had the highest overall mean seed yield in field trials grown in conjunction with this study. In order to assess relationships between traits measured in the greenhouse and those measured in the field, correlations were run between greenhouse means and field means for 25 genotypes to determine relationships which existed among these plant traits. The genotypes were also split into determinates and indeterminates to allow comparisons among stem termination types. Several of these correlations are presented in Table 8.

Overall, no greenhouse means had significant correlations with field means for seed yield. Some trends were noted, however, within stem termination types. The overall mean seed yield was positively correlated with the relative performance for height (HT-REL PRF) among indeterminates, while it was negatively correlated with percent nitrogen in the control treatment (%N-No straw) among determinates. Seed yield, in the wheat residue environments, among determinates was positively correlated with percent nitogen in 2% straw treatments (%N-2% straw) and the relative performance for percent N (%N-REL PRF), and was negatively correlated with the relative performance for dry weight (DWT-REL PRF) and %N-No straw. Indeterminates showed positive

Table 8. Correlations between line means in the greenhouse and line means in the field for seed yield, plant height, and percent nitrogen, by treatment and stem termination type.

GREENHOUSE‡ MEANS	FIELD MEANS†								
	Environment						REL PRF§		
	PAR¶	COL	PIT	F	R	Mean	COL	PIT	Mean
	Seed yield								
DWT									
2% straw	-.13	0	-.10	.21	-.20	-.10	-.47**	0	-.29
D	-.25	.26	-.31	.39	-.29	-.13	-.59**	-.18	-.43
I	.05	-.47	.47	-.04	.05	.03	-.31	.52*	.14
REL PRF§	.16	-.17	-.05	.13	-.24	.07	-.31	.22	.32
D	.01	-.02	-.56**	.26	-.62**	-.36	-.60**	-.68***	-.73***
I	.29	-.42	.54*	-.02	.15	.21	-.10	.35	.19
HT									
2% straw	-.29	.15	-.11	.20	-.10	-.08	-.17	-.17	-.22
D	-.47*	.22	.18	.36	.10	.10	.06	-.04	.02
I	.06	.65**	.07	.59*	.34	.48	.05	-.21	-.10
REL PRF	0	.38	.21	.33	.27	-.30	.21	-.04	-.21
D	-.36	.14	-.35	-.07	-.15	-.24	-.01	-.19	-.05
I	.30	.39	.34	.58**	.38	.61**	.09	-.19	-.12
% N									
No straw	.03	-.12	-.04	.04	-.14	-.08	-.09	-.24	-.20
D	.09	-.38	-.60**	-.17	-.66**	-.54**	-.40	-.60**	-.58***
I	-.23	-.18	.45	-.03	.36	.07	.11	.36	
2% straw	.25	.31	.14	-.01	.34	.21	.25	.38*	.38*
D	-.45	.43	.28	-.11	.59**	.32	-.45	.59**	.61**
I	-.04	.26	.10	.29	.18	.31	-.04	-.02	-.04
REL PRF	.23	.27	.10	-.06	.31	-.16	.23	.39**	.36**
D	.53*	.47*	.44	-.05	.72***	.45	.53*	.70**	.71***
I	-.06	.27	.07	.24	.04	.23	-.06	-.13	-.16
	Plant height								
HT									
No straw		-.35*	-.42**	-.31	-.44**	-.39*	-.26	-.48**	-.55***
D		.05	-.07	.19	-.09	.06	-.33	-.53**	-.58**
I		.08	-.07	.03	0	.01	-.21	.13	-.02
2% straw		.38*	-.43**	-.34*	-.41**	-.38*	-.17	-.28	-.36*
D		-.03	-.16	-.06	-.23	-.14	-.26	-.27	-.33
I		-.45*	-.47*	-.27	-.27	-.28	-.12	0	-.07
REL PRF		-.33	.19	-.15	.26	.21	.21	.40**	.45**
D		-.43	-.28	-.32	-.08	-.21	.23	.53**	.53**
I		-.10	-.52*	-.38	-.33	-.37	.11	-.15	-.06
	% Leaf nitrogen								
% N									
2% straw	.14		.05	.28	-.07	.13	.40**	-.05	-.31
D	.32		-.13	.40	-.15	.17	-.67**	-.06	-.48*
I	-.14		.33	.03	.12	.09	.15	-.05	.06
REL-PRF	.02		-.12	.13	-.22	-.05	-.36*	-.06	-.29
D	.20		-.30	.26	-.25	.02	-.60**	-.07	-.44
I	-.27		.25	-.13	0	-.07	.27	-.12	.04

*,**,*** Significant at the .10, .05, and .01 levels, respectively. No. of means is 25, for treatments, 13, for determinants within treatments, and 12, for indeterminates within treatments.

† PAR=Parsons location, PIT=Pittsburg location, F=fallow environment, R=wheat residue environment.

‡ DWT=dry weight, HT=seedling height, %N=percent nitrogen in tissue, D=determinates, and I=indeterminates.

§ REL PRF=relative performance, calulated as a percentage of the control mean when a genotype was grown in a straw environment.

¶ Seed yield and plant height contain means from fallow envionment only.

correlations for plant height in 2% straw treatments (HT-2% straw) and HT-REL PRF in the fallow environments. The relative performance of determinates for seed yield was negatively correlated with DWT-REL PRF and %N-No straw and positively correlated with %N-2% straw and %N-REL PRF.

Overall mean plant height in the field was negatively correlated with seedling height in the control treatments (HT-No straw) and in the straw treatments (HT-2% straw). These correlations are a result of indeterminates exhibiting shorter seedling height but taller mature height than determinates. The relative performance of determinates for mature plant height was positively correlated with HT-REL PRF and was negatively correlated with HT-No straw. Percent nitrogen measured in the greenhouse, did not correlate well with percent nitrogen measured in the field.

Table 9 depicts the mean effects of three soybean genotypes, three cultivars of wheat straw and four concentrations of wheat straw on soybean seedling dry matter production and height. Genotypic effects are similar to those obtained in the previous two studies. The indeterminate line, K77-46-62, was the shortest line, but had the greatest dry matter production. In this study Forrest was significantly taller than Essex.

A significant genotype x treatment interaction occurred between the control treatment and the wheat-straw treatments for dry weight. This was primarily due to Forrest suffering a greater reduction in dry matter production (46%) than Essex (36%) or K77-46-62 (32%). This differential response did not occur for these lines in the Greenhouse evaluation study.

Table 9. Effects of three soybean lines, straw from three cultivars of straw, and four concentrations of wheat straw mixed with soil on soybean seedling growth in the greenhouse.

Effect	Plant traits†	
	Seedling height	Dry weight
	-- cm --	-- g --
LINE		
Forrest	9.6 a	.96 b
Essex	8.5 b	.96 b
K77-46-62	8.0 c	1.05 a
Straw variety		
Newton	8.3 a	.89 b
McNair	8.4 a	.93 ab
TAM 105	8.7 a	.96 a
Straw Concentration		
Control	10.6 a	1.53 a
.5 %	8.8 b	1.04 b
1.5 %	8.4 c	.88 c
3.0 %	8.3 c	.88 c

† Means followed by the same letter within a column and effect are not statistically different according to LSD proceedure at the .05 level of probabiltity.

The wheat cultivars exhibited significant differences in their effects on soybean seedling dry weight, but not seedling height. No significant wheat cultivars x soybean genotype interactions or wheat cultivar x straw concentration interactions occurred for either trait.

All wheat straw concentrations reduced seedling growth when compared with the control mean. The 1.5% and 3% concentrations significantly reduced seedling growth more than the .5% concentration, but there no significant differences between the two higher concentrations.

CONCLUSIONS

While the magnitude of genotype x tillage treatment interaction for soybean yield indiates that genetic gain would be improved by the testing of lines in double-crop environments, the need for a specialized breeding scheme is unclear. Yield reductions in wheat residue environments were moderate (6%) and probably do not warrant a special program for double-crop cultivar development. Cultural practices which would improve soil physical and chemical conditions for plant growth in double-crop systems would probably overcome most of the problems associated with double-crop soybean production.

The incorporation of indeterminate growth, through selection or backcrossing, should improve soybean cultivars for double-crop production, as indeterminate lines may be higher yielding and be more yield stable than determinate lines in double-crop stituations.

Cold water extracts derived from wheat straw did not reduce soybean seedling growth in greenhouse pots. Seedling growth was substantially reduced, however, when seedlings were grown in pots mixed with wheat straw. The percent nitrogen in seedling tissue was also substantially reduced in wheat straw treatments. These results indicate that phytotoxic substances leached from wheat straw do not play an important role in the early stunting of soybean seedlings in double-crop environments, and that nitrogen availability may be a more important limiting factor in the early growth of soybeans in double-crop environments. These results do not discount possible effects of leachates when straw is in close proximity to plant parts or the effects of toxins released during the decomposition of wheat straw.

Overall, the greenhouse technique was not effective in identifying genotypes tolerant to the effects of wheatstraw. Although differential responses occurred amoung soybean genotypes for seedling height, dry matter production, and percent tissue nitrogen when grown in the greenhouse, these responses were not well correlated with field performance. Also, genotypes which exhibited a greater relative performance for one trait generally did not show high relative performances for other traits.

While N immobilization appears to be a more important factor limiting growth of soybean seedlings in the wheat straw treatments, than leachates from undecomposed straw, selection for percent N among genotypes, which were essentially non-nodulating, was not effective in identifying lines tolerant to the effects of wheat straw. This indicates that there may not be substantial genetic differences among lines in their ability to uptake N from soil. Since field means and greenhouse means were not well correlated, genetic differences may occur amoung genotypes for N-fixing ability. Therefore, selection of lines for N-fixing ability might be a possible solution in overcoming the early stunting of soybean seedlings in double-crop environments.

Wheat cultivars did not exhibit substantial differences in their effects on soybean seedling growth. Differences which did occur may be due to different C:N ratios among the wheat samples used. These C:N ratios may be independent of cultivars and due to other factors which affect the levels of nitrogen in plant tissue

, such as soil fertility levels and maturity at harvest. Implications are, however, that the choice of a wheat cultivar to precede soybeans will not effect the success of wheat-soybean double-crop systems.

The level of straw concentration affects soybean seedling growth. Implications are that methods of residue management which reduce the concentration of wheat straw in soil will improve soybean seedling growth in double-crop environments.

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CHAPTER II

COMPARISON OF THE LATTICE SQUARE DESIGN AND RANDOMIZED COMPLETE BLOCK DESIGN IN SOYBEAN BREEDING TRIALS

ABSTRACT

Data from a genotype x production system interaction study, consisting of 25 soybean [Glycine max (L.) Merr.] lines, arranged in a lattice aquare (LSQ) design and grown in five environments, were used to compare the relative efficiency (RE) of the LSQ design to the randomized complete block design (RCBD), and to evaluate the effect of LSQ analysis upon line selection for several plant traits.

The average RE's for seed yield and seedling leaf nitrogen were 140 and 145%, respectively. In general, mature plant height, 100 seed weight, and seed quality did not benefit from LSQ analysis, as these are more qualitative traits and less influenced by field heterogeneity. The range in RE's were: 101 to 201% for seed yield, 90 to 108% for plant height, 93 to 125% for 100 seed weight, 76 to 101% for seed quality, and 125 to 156% for seedling leaf nitrogen.

The rank correlation between line means obtained by use of LSQ analysis, and line means obtained by RCBD analysis decreased as the RE's increased. Rank correalations ranged from .88 to .99 for seed yield, and from .64 to .85 for percent leaf nitrogen. Therefore, when substantial gains in precision are realized, LSQ analysis would provide better estimates of line means than RCBD analysis and would provide a breeder more confidence in selecting superior lines.

When gains in precision were realized LSQ analysis reduced the least significant difference (LSD), coefficient of variation (C.V.), and affected the significance of the test.

In the combined analysis, over all environments, LSQ analysis provided better estimates of genotype x environment interactions than the RCBD analysis. This would aid a breeder inselection lines over an number of locations and years.

The ability of the LSQ design to control field heterogeneity in two direcxtions was determined to be a desirable characteristic, as the direction in which major variability was lain could not be predicted before hand. When major variability was lain in two directions the LSQ achieved maximum efficiency.

Additional index words: Experimental design, relative efficiency, line selection, genotype x environment interactions, *Glycine max*, plant traits.

INTRODUCTION

A popular experimental design used by plant breeders is the randomized complete block design (RCBD). This design is flexible in the number of entries and the number of replicates which may be used. Field dimensions are also flexible; however, the efficiency of the design is affected by the ability of the experimenter to group the replicates into homogeneous units in the field. When the replicates are effectively grouped into homogenous units, gains in precision are realized from the RCBD over the completely randomized design. In soybean breeding trials, with a large number of entries in a trial, the RCBD may suffer from a high error variance associated with field heterogeneity. The selection of the top few lines and their relationship to check varieties in the test becomes unclear. One way to improve the accuracy of soybean breeding trials might be through the use of incomplete block designs. Incomplete block designs would reduce the effects of field heterogeneity by grouping treatments into blocks smaller than complete replicates.

Lattice designs are incomplete block designs which have the desirable property that incomplete blocks are still arranged into complete replicates, allowing analysis by method of randomized complete blocks (15). However, these designs have severe limitations on the number of replicates and number of entries allowed, with some restrictions on field dimensions. The number of treatments must be an exact square, and the number of plots along one side of a complete replicate is the square root of this number. The actual field dimensions, however, depends upon the size of the plot and need not be square because the plots, themselves, need not be square. The plots, though, must be arranged in a square, or lattice, fashion. The number of treatments and number of replicates allowed for some balanced lattice designs are summarized in Table 10. With balanced lattice designs, treatments are compared with equal precision, which is desirable in plant breeding trials.

The number of replicates required for most of these designs are prohibitive for most plant breeding trials. With a fixed number of plots, genetic gain is maximized by increasing the number of lines to be evaluated. This necessitates a minimum number of replicates. Currently, in advanced soybean breeding trials at Kansas State University, 20 to 40 lines are evaluted in tests arranged in a randomized complete block design, and three replicates are considered optimum for the best use of resources. A 5*5 balanced lattice square design would meet requirements for the number of treatments and the number of replicates desired in these trials, and gains in precision over randomized blocks would be expected. This design also has the desirable property that field heterogeneity is contolled in two directions, much like a latin square design.

Precision in experimental design is the size of the difference between two treatments were statistical differences can be detected, and the relative efficency of two designs measures the relative amount of replication required to achieve equal amounts of precision (5).

The use of lattice designs in field plot data has often resulted in substantial gains in precision over the RCBD.

Table 10. Required number of treatments, units per block, and replications for some balanced lattice designs.

Number of treatments	9	16	25	49	64	81
Units per block (k)	3	4	5	7	8	9
Replicates	4*,8	5*,10	3*,6	4*,8	9	5*,10

* Allowed for lattice square designs in (k+1)/2 replicates.

Source: W.G. Cochran and G.M. Cox. Experimental Design. 2nd ed. pg. 396,484.

Knowles (10) reported efficiencies of lattice designs for several workers in annual crops. Efficiencies reported were: 114-365% in corn (4), 155-224% in oats (8), and 109-148% for various cereal crops (3,11,13). Wilse (14) compared several types of lattice designs in forage crop trails and found the average efficiency to be 164%, with a range of 102 to 638%. Kempthorne (9) reported gains in information over randomized complete blocks with the use of a 5 x 5 balanced lattice square design. These gains in precision were: for potatoes, 34, 54, 52, 163, and 42%; and for barley, 67, 75, 18, 12, 31, and 171%.

The purpose of this paper is to compare the relative efficiency of a 5 x 5 balanced lattice design to a randomized complete block design in soybean breeding trials, and to evaluate the effect of lattice square analysis line selection.

MATERIALS AND METHODS

The data presented were taken from soybean plots grown in five environments in southeastern Kansas during 1982 and 1983. These environments were part of genotype x production system interaction study.

The study was arranged in a split-plot design over two years at three locations. The locations were: 1982, Columbus, Kansas; 1983, Pittsburg and Parsons , Kansas. Whole-plots consisted of two tillage treatments. These treatments provided a comparsion of soybeans grown in fallow ground and soybeans grown in wheat residue. Planting dates for both treatments were in early July following winter wheat harvest. The sub-plot treatments consisted of 22 randomly chosen soybean lines from F5 progeny rows and three check varieties: 'Essex', 'Forrest', and K77-46-62. The sub-plot treatments were arranged in a 5 x 5 balanced lattice square design. Whole-plot treatments could, therefore, be considered as separate environments for purposes of comparing the lattice design and a randomized complete block design. Only five of the available six environments are used. The wheat residue treatment at Parsons, Kansas, in 1983, had to be deleted from the study, due to severe drought.

In the two environments during 1982, the lines were assigned at random to plots in the basic plan, but the complete randomization as recommended by Yates (15) was not followed. The complete randomization would have included the additional randomization of rows and of columns within each replication.

Although the complete randomization would have been prefered, the lack of the additional randomization probably has not greatly impared the validity of the comparisons of the two designs. Bliss and Dearborn (2) also failed to use the complete randomization. They stated that the absence of the complete randomization probably did not affect the comparisons they made to any appreciable extent. In 1983, the complete randomization was performed on the remaining three environments.

Data collected in 1982 consisted of plant height and seed yield. In 1983 additional measurments consisted of weight per 100 seeds, seed quality, and percent leaf nitrogen. Data for the five environments were analyzed in a lattice square as described by Cochran and Cox (7), and by method of randomized complete blocks. Relative efficiency (RE) of the lattice square design as compared with the RCBD was calculated using the formula described by Cockran and Cox (5)):

$$RE = \frac{(n_1+1)(n_2+3)\ s_2^2}{(n_1+3)(n_2+1)\ s_1^2},$$

where s_1^2 and s_2^2 are the error variances for the RCBD and the lattice square design, respectively, and n_1, n_2 are the degrees of freedom for the error variances of the RCBD and the lattice square design, respectively.

Error variances were also calculated for two partially balanced lattice designs: if rows of the basic plan had been chosen as blocks (LAT/ROW), and if columns of the basic plan had been chosen as blocks (LAT/COL). Relative efficiencies of the two partially balanced designs, as compared to the lattice square design, were then calculated to assess the advantages of controlling field heterogeneity in two directions.

A combined analysis was also performed across environments, for the RCBD and the lattice square design. Environments and genotypes were considered random effects.

RESULTS AND DISCUSSION

Table 11 presents comparisons of the relative efficiency of the lattice square (LSQ) design to the randomized complete block design (RCBD), the LSQ design vs. a triple lattice with rows of the basic plan chosen as blocks (LAT/ROW), and the LSQ design vs. a triple lattice with columns of the basic plan chosen as blocks (LAT/COL), for five plant traits measured in several environments. Substantial gains in precision were realized with the use of the lattice square design over the RCBD for seed yield, percent leaf nitrogen, and 100 seed weight, but not plant height or seed quality.

Substantial gains in precision were realized in three of the five environments for seed yield with the use of the lattice square design. In no instance was the lattice square design less efficient than the randomized block design. The average relative efficiency was 140 percent with a range of 201 to 101%. These gains in precision mean that six replications of the RCBD would have been required to provide the same amount of precision as three replications of the lattice square design in the Columbus-fallow environment. Five replications of the randomized block design would have been required in the Columbus-residue environment, and four replications of the RCBD would have provided as much precision as the lattice square design in the Pittsburg-fallow environment.

Substantial gains in precision were not realized in any of the environments for plant height, and in the Pittsburg-fallow environment, the lattice square design was less efficient than

Table 11. The relative efficiency of a 5x5 balanced lattice square design, as compared with a RCBD, a triple lattice with rows chosen as blocks (LAT/ROW), and a triple lattice with columns chosen as blocks (LAT/COL) for five plant traits measured in various environments.

Environment	RCBD	LAT/ROW	LAT/COL
	%	%	%
	------ Seed Yield ------		
Columbus, fallow	201	109	181
Columbus, residue	163	162	142
Pittsburg, fallow	101	102	103
Pittsburg, residue	130	134	107
Parsons, fallow	103	106	100
Average efficiency	140	123	127
	------ Plant height -----		
Columbus, fallow	104	105	106
Columbus, residue	108	107	106
Pittsburg, fallow	90	84	109
Pittsburg, residue	108	110	107
Average efficiency	103	102	107
	---- 100 Seed weight ----		
Pittsburg, fallow	93	88	109
Pittsburg, residue	125	122	123
Parsons, fallow	107	103	110
Average efficiency	108	98	114
	----- Seed quality------		
Pittsburg, fallow	101	105	101
Pittsburg, residue	101	103	103
Parsons, fallow	76	85	85
Average efficiency	93	98	96
	---- % Leaf nitrogen-----		
Pittsburg, fallow	147	205	90
Pittsburg, residue	156	155	107
Parsons, fallow	151	133	158
Parsons, residue	125	129	111
Average efficiency	145	156	117

the RCBD. The average relative efficiency for plant height was 103%.

Results for 100 seed weight ranged from a loss of accuracy in the Pittsburg-fallow environment, to a substantial gain in the Pittsburg-residue environment. The average gain in precision for seed weight was 108%, with a range of 93 to 125%. The lattice square design had a poor showing for seed quality, with an average RE of 93 percent. In the Parsons-fallow environment, the RE was only 73 percent.

Substantial gains in precision were realized in all four environments for percent leaf nitrogen. The average gain in precision of the lattice design over the randomized block design was 45%, with a range of 25 to 56%.

In three instances a loss of accuracy with the use of the lattice square design over the RCBD was noted. Most authors contend that, with analysis of the lattice square using recovery of inter-block information, the lattice designs can be no less efficient than the randomized complete block design (1,2,6,15).

This conclusion is based upon two assumptions. First, since the lattice square design may be analyzed as randomized complete blocks, when analysis by method of lattice squares is proven to be less efficient than RCBD analysis, lattice square analysis should be abandoned, and analysis by method of randomized blocks should be employed (2,15). This approach is inconsistant with good experimental analysis, and should not be used. It is appropriate, however, to decide before data is collected by which method (RCBD or lattice) a variable should be analyzed.

The second assumption is that the inter-block comparisons in no case would be more precise than the intra-block comparisons (6). That is, since a component of the variance among blocks is the intra-block variation, the variance among blocks could not be less than the intra-block variance. Therefore, in the extreme case where variation due to blocks was non-existent, the analysis would automatically reduce to that of randomized blocks. In practice, however, the variation among incomplete blocks was often less than the intra-block variance, and inefficiencies occurred.

Plant height and seed weight are more qualitative traits than seed yield, percent leaf nitrogen, or 100 seed weight, and therefore are less influenced by field heterogeneity. This explains why these plant traits did not benefit from lattice square analysis. Therefore, qualitative traits, which are not likely to benifit from the use of incomplete blocks, should be analyzed by method of randomized blocks. This would insure that these traits would be compared with at least as much precision as randomized blocks and avoid inefficiencies which could occur with lattice square analysis.

The advantage of controlling field heterogeneity in two directions can be seen by comparing the RE's of the triple lattice with rows chosen as blocks (LAT/ROW) and the triple lattice with columns chosen as blocks (LAT/COL), (Table 11). If the RE of the LAT/ROW design is less than the RE of the LAT/COL design, then the lattice square design was more efficient at partitioning out variation among rows than variation among columns. Conversely, if the RE of the LAT/COL design is less than the RE of the LAT/ROW design, then the lattice square design was more efficient at partitioning out variation among columns than variation among rows.

In the three environments where substantial gains in precision were realized for seed yield , the ability of the lattice design to partition row effects was primarily responsible for gains in precision in the Columbus-fallow environment, while the ability to partition column effects was primarily responsible for gains in precision in the Pittsburg-residue environment. In the Columbus-residue environment the partitioning of both row and column effects substantially improved the precision of the test. The analysis of 100 seed weight in the Pittsburg-residue environment was also enhanced by the partitioning of both row and column effects.

Increased accuracy for percent leaf nitrogen was primarily due to the partitioning of row effects in the two Pittsburg environments, while both row and column effects were important in the two Parsons environments.

It is interesting to note that in these tests the direction in which field heterogeneity was lain could not be predicted before hand. Therefore, the ability of the lattice square design to control field heterogeneity in two directions adds to the attractiveness of this design.

In lattice square designs two sources of variation are partitioned among incomplete blocks, i.e. among rows and among columns. If either one of these mean squares are less than the within block variation, then inefficiencies for that block effect will result. The other block effect may, however, result in gains in precision and overcome the loss of information of the first block effect.

Table 12 compares the row and column mean squares to the intra-block mean square in cases where the row or column mean square was less than the intra-block mean square.

In three out of four cases the loss of information due to an incomplete block effect resulted in the lattice square design being less efficient than the randomized complete block design. In the Parsons-residue environment for seed quality, both row and column effects resulted in a loss of information and the RE was the lowest for any trait in any environment. In the Pittsburg-fallow environment for leaf nitrogen the substantial gain in precision achieved by the column effect overcame a loss of information due to the row effect and the lattice square design was more efficient than the RCBD. The ability of the lattice square to partition both row and column effects was a definite advantage in this case.

Effects of Gains in Precision

The analysis by method of lattice squares results in the adjustment of treatment totals for the blocks in which a treatment occurs. Therefore, it would be expected that there would be differences between the ranking of the means in the lattice square design and the randomized complete block design. A measure of the degree of concurrence between the ranking of means between the two types of design may be given by Spearman's rank correlation coefficent (12). The use of the lattice design would also

Table 12. Comparisons of the row and column mean squares to the intra-block mean square when one of the incomplete block mean squares was less than the intra-block mean square, and its effect on the relative efficiency (RE) of the lattice square design vs. the RCBD.

Environment	Plant trait	Row Mean square	Column Mean square	Intra-block Mean square	RE
Pittsburg-fallow					
	Plant height	4.6	1.3	2.8	90
	100 Seed weight	.62	.24	.38	93
	Leaf nitrogen	.02	.13	.03	153
Parsons-residue					
	Seed quality	.24	.24	.41	76

affect the coefficient of variation (C.V.), least significant difference (LSD and the significance of the test.

Table 13 depicts the effect of lattice square analysis on seed yield means. The mean rank correlation decreased with gains in precision, indicating that there was a greater change in the rankings when substantial gains in precision were realized. The mean rank correlation ranged from .88 in the Columbus-fallow environment, which had a RE of 201%, to .99 in the Parsons-fallow environment, which had a RE of 103%. Most adjustments resulted in a change of a only a few positions in ranks. However, sometimes larger changes in ranks occurred.

Of particular interest was how the analysis by method of lattice squares affected the significance of the test, as indicated by the p-values. In the Columbus-fallow environment the variance ratio for the line effect was significant ($p<.05$) when analyzed by method of randomized blocks; but was not significant in this environment when analyzed by method of lattice squares. In contrast, the line effect for seed yield in the Columbus-residue environment was significant when analyzed by lattice squares, but not significant for RCBD analysis. The variance ratio was highly significant for both designs in the other environments, with a tendency for the p-values to be higher with the lattice square analysis.

The differential response of p-values to method of analysis may be rationalized by comparing these responses to the range of the means in a test. In the Columbus-fallow environment, the result of gains in precision was to adjust the highest means down and the lowest means up. Therefore, there was less difference

Table 13. Comparison of the line means and ranks (RK) as obtained by the use of the RCBD, and the adjusted line means as obtained by lattice square analysis for seed yield in five environments.

Line	Columbus								Pittsburg								Parsons			
	Fallow				Residue				Fallow				Residue							
	RCBD		LSQ		RCBD		LSQ		RCBD		LSQ		RCBD		LSQ		RCBD		LSQ	
	Kg/ha	RK	Kg/ha	RK	Kg/ha	RK	Kg/ha	RK	Kg/ha	RK	Kg/ha	RK	Kg/ha	RK	Kg/ha	RK	Kg/ha	RK	Kg/ha	RK
Essex	2376	4	2188	3	1858	17	1911	14	1936	3	1942	5	1476	20	1468	21	1312	8	1298	7
Forrest	2009	15	2115	10	1702	23	1808	20	1870	9	1858	9	1635	17	1789	10	1379	5	1400	4
K77-46-62	2438	2	2244	2	1992	12	1961	12	1837	11	1809	13	1882	5	1955	3	1173	17	1161	19
K77-46-19	1996	17	2067	16	1824	20	1843	17	1726	17	1759	16	1794	11	1838	6	1240	13	1225	13
K77-46-23	2379	3	2188	3	1916	13	1826	18	1689	19	1688	20	1433	21	1458	22	1031	22	1040	23
K77-46-40	2130	9	2160	5	2233	3	2024	10	1933	4	1968	3	1618	19	1724	12	1427	4	1382	5
K77-46-42	1808	22	1874	21	2165	6	2158	6	1819	12	1804	14	1905	8	1890	4	1275	10	1277	9
K77-46-45	2474	1	2375	1	1867	16	1572	24	1611	23	1615	23	1023	25	1056	25	1185	16	1199	16
K77-46-78	2023	14	2102	13	1829	19	1793	22	1657	22	1658	22	1177	24	1214	23	1059	21	1083	21
K77-50-09	1828	21	1846	24	1444	25	1570	25	1554	24	1554	25	1249	23	1214	24	1313	7	1284	8
K77-50-33	1736	24	1849	23	1878	14	1919	13	1742	16	1757	17	1756	12	1715	14	1487	2	1535	1
K77-50-53	1800	23	1902	20	2144	7	2177	4	2206	1	2170	1	2105	1	2040	1	1466	3	1457	3
K77-50-59	2160	7	2077	14	2339	1	2444	1	1679	21	1662	21	1433	21	1574	20	1151	19	1190	18
K77-50-63	2210	5	2144	7	2230	5	2165	5	1812	14	1831	11	1627	18	1667	15	1495	1	1486	2
K77-50-73	2137	8	2113	11	2231	4	2204	3	1915	5	1944	4	1864	6	1819	7	1103	20	1097	20
K77-63-44	2113	10	1990	18	2105	8	1963	11	1726	17	1735	18	1814	8	1791	9	1262	11	1257	11
K77-63-50	2102	13	2128	9	2295	2	2235	2	1897	6	1894	6	1712	14	1718	13	1333	6	1303	6
K77-63-67	1594	25	1834	25	1824	20	1857	16	1845	10	1838	10	1667	16	1607	18	1008	24	1023	24
K77-63-76	1935	18	1866	22	1949	24	1701	23	1547	25	1537	25	1740	13	1639	17	1013	23	1053	22
K77-63-84	1868	20	2007	17	2010	11	2140	8	1794	15	1812	12	1813	10	1735	11	914	25	938	25
K77-63-87	2107	11	2154	6	2058	9	2146	7	1876	8	1879	7	1825	7	1588	19	1238	14	1234	12
K77-66-03	2007	16	2109	12	1935	18	1891	15	1814	13	1800	15	1892	4	1890	4	1160	18	1199	16
K77-66-32	2175	6	2129	8	1868	15	1806	21	1688	20	1692	19	1709	15	1666	16	1204	15	1200	15
K77-66-42	2104	12	2072	15	2165	6	2158	6	2200	2	2009	2	1905	3	1808	8	1298	9	1272	10
K77-66-50	1898	19	1885	19	2019	10	2117	9	1887	8	1879	7	1963	2	2024	2	1258	12	1209	14
LSD(.05)	447		318		530		418		254		255		451		399		227		274	
MEAN	2057		2057		1962		1962		1804		1803		1675		1677		1231		1232	
CV (%)	13.3		9.0		16.5		12.5		8.6		8.4		16.4		14.0		13.7		13.2	
P-VALUE	.0212		.1000		.1510		.0258		.0016		.0071		.024		.0030		.0028		.0155	
RANK CORR†	.88				.89				.98				.87				.99			

† Spearman correlation between the ranking of means for the two types of design.

among the adjusted means and the variance ratio was non-significant. In the Columbus-residue environment, the range among means stayed nearly the same during adjustments, and the result of gains in precision was to reduce the error variance, which increased the significance of the line effect. It should be noted that these two environments were the ones in which the complete randomization was not followed. Bias in the placement of plots may have influenced the results.

Higher p-values for lattice square analysis may be a result of differing degrees of freedom for the error variance for the two types of design. The lattice square analysis would require a higher variance ratio for a given level of significance than the RCBD. Therefore, if the variance ratios are approximately the same, the p-values for lattice square analysis will be higher than the p-values for RCBD analysis.

Substantial gains in precision were not realized for plant height or seed quality in any environment. Theretore, the effects of lattice square analysis upon test statistics were minimal. Spearman's rank correlation was .99 in all environments for plant height,indicating a high level of concurrence between the ranking of the means in the two types of design. This is not to say that large adjustments of means did not occur. For example, the mean height of line K77-46-42, in the Columbus-fallow environment, was decreased from 119 cm in the RCBD analysis to 102 cm in the lattice square analysis. This resulted in a change from rank 1 to rank 4.

The implication of this observation is that, even if substantial gains in precision are not realized with the lattice square analysis, the elimination of incomplete block effects from line totals allows a better estimate of line means. Therefore, a breeder would have more confidence in the selection of lines.

Mean rank correlations for seed quality was .99 in both Pittsburg environments, and was 1.00 in the Parsons environment. In the latter case both row and column mean squares were less than the intra-block variance (Table 12) and no block adjustments were made.

Mean rank correlations for seed weight were .99 in the Pittsburg-fallow and in the Parsons-fallow environments, where substantial gains in precision were not realized, and was .98 in the Pittsburg-residue environment, where a substantial gain in precision was realized.

The lattice square analysis had a drastic effect on the adjustment of line means for percent leaf nitrogen (Table 14). The ranking of means changed more for this trait than for any other trait as indicated by the rank correlations between the two designs. Rank correlations ranged from .85 in the Pittsburg-fallow environment to only .64 in the Parsons-fallow environment. The significance of the test was increased in three out of four environments even though the range in the means was substantially reduced in the Pittsburg-fallow environment. The elimination of block effects from treatment totals, therefore, provided a much better estimate of line means for this trait than would have been obtained from use of the RCBD.

Gains in precision always resulted in lower LSD(.05) values and lower C.V.'s for the traits measured. This would be expected

Table 14. Comparison of the line means and rankings as obtained by use of the RCBD, and the adjusted line means as obtained by lattice square (LSQ) analysis for percent leaf nitrogen in four environments.

LINE	Pittsburg								Parsons							
	Fallow				Residue				Fallow				Residue			
	RCBD		LSQ		RCBD		LSQ		RCBD		LSQ		RCBD		LSQ	
	%	rank	%	rank	%	rank	%	rank	%	rank	%	rank	%	rank	%	rank
Essex	4.77	7	4.73	10	4.90	8	4.97	3	4.69	21	4.77	19	5.24	6	5.22	8
Forrest	4.56	20	4.58	19	4.81	12	4.83	13	4.83	13	4.88	6	4.72	25	4.73	25
K77-46-62	4.68	15	4.73	10	5.03	4	4.93	6	4.86	10	4.80	14	5.24	6	5.29	3
K77-46-19	4.70	13	4.84	5	4.79	14	4.85	11	4.83	13	4.77	19	4.96	20	5.01	17
K77-46-23	4.49	23	4.61	17	4.60	24	4.74	19	4.60	24	4.68	24	5.19	10	5.21	10
K77-46-40	4.84	4	4.74	9	4.70	20	4.72	20	4.89	9	4.88	6	5.13	15	5.14	12
K77-46-42	4.72	11	4.65	14	4.93	7	4.82	14	4.74	19	4.86	8	5.29	3	5.24	6
K77-46-45	4.73	10	4.96	12	4.76	15	4.66	23	4.61	23	4.60	25	4.95	21	4.84	23
K77-46-78	4.84	4	4.90	2	4.75	16	4.79	15	4.76	18	4.80	14	5.23	8	5.11	14
K77-50-09	4.50	22	4.59	18	5.04	3	5.07	1	4.97	5	4.79	17	5.17	12	5.11	14
K77-50-33	4.98	1	4.89	3	4.68	21	4.59	25	4.85	11	4.83	10	5.17	12	5.28	4
K77-50-53	4.84	4	4.85	4	5.10	2	4.97	3	5.03	1	5.05	1	4.97	18	4.96	20
K77-50-63	4.65	16	4.57	20	5.01	5	4.94	5	4.90	8	4.76	21	5.06	16	5.18	11
K77-50-59	4.74	9	4.62	16	4.72	18	4.79	15	4.98	4	4.97	3	5.29	3	5.24	6
K77-50-73	4.65	17	4.68	13	4.59	25	4.76	17	4.65	22	4.83	10	5.35	1	5.31	2
K77-63-44	4.58	19	4.56	21	4.65	23	4.75	18	5.01	3	5.00	2	4.97	18	5.01	17
K77-63-50	4.80	6	4.95	1	4.68	21	4.90	8	4.60	24	4.79	17	4.73	24	4.75	24
K77-63-67	4.47	24	4.47	25	4.71	19	4.64	24	4.93	7	4.79	17	4.83	22	4.85	22
K77-63-76	4.54	21	4.56	21	4.84	10	4.93	6	4.83	13	4.86	8	5.24	6	5.25	5
K77-63-84	4.72	11	4.77	7	4.81	12	4.68	22	4.77	17	4.75	22	4.99	17	5.11	14
K77-63-87	4.59	18	4.50	24	4.75	16	4.69	21	5.02	2	4.95	4	4.83	22	4.92	21
K77-66-03	4.44	25	4.52	23	4.96	6	4.90	8	4.70	20	4.81	12	5.17	12	5.22	8
K77-66-32	4.75	8	4.77	7	4.84	10	4.87	10	4.96	6	4.92	5	5.30	2	5.40	1
K77-66-42	4.70	13	4.65	14	4.84	10	4.84	12	4.79	16	4.71	23	5.14	14	5.05	16
K77-66-50	4.92	2	4.78	6	5.15	1	5.02	2	4.81	15	4.80	14	5.22	9	5.18	11
LSD(.05)	.37		.30		.46		.37		.32		.26		.52		.47	
MEAN	4.69		4.70		4.83		4.83		4.83		4.83		5.10		5.09	
CV (%)	4.8		3.8		5.8		4.6		3.8		3.1		6.2		5.5	
P-VALUE	.2848		.1239		.5912		.5406		.0022		.0006		.3888		.6037	
RANK CORR†		.85				.77				.64				.93		

† Spearman correlation between the ranking of means for the two types of design.

due to the influence of the determined error variance in the formulas for calculating these test statistics. The mean for a test was not affected by lattice square analysis. Small differences shown are due to rounding errors in calulating the means.

Combined Analysis

The effects of lattice square analysis on the overall line means are given in Table 15 for the five traits measured. The mean, LSD(.05) value, the rank correlation between the two designs, and the p-values for the significance of the line effect and the line x treatment interaction are also given.

The ranking of means changed more for percent leaf nitrogen than for any other variable, as indicated by the rank correlation coefficients. The lattice square analysis resulted in changes in mean seed yield for all treatments, with some substantial changes in the ranks. The effect of lattice square analysis on the overall line means was minimal for seed weight, seed quality, and plant height.

Since environments and lines were considered random effects in the analysis of variance, it is important to ascertain the effect of lattice square analysis upon the line x environment interaction. The genotypic and interaction components of variance for each plant trait in the combined analysis of both designs are given in Table 16. The magnitude of the genotypic component of variance was increased for seed yield and decreased for percent nitrogen, while the interaction component was decreased for seed yield but was increased for plant height. The effects of LSQ analysis on the components of variance for plant height, seed

Table 15. Comparison of overall line means and rankings (RK) as obtained by use of the RCBD and lattice square (LSQ) analysis for five plant traits.

LINE	Seed yield				Plant height				Leaf nitrogen				Seed weight				Seed quality			
	RCBD		LSQ		RCBD		LSQ		RCBD		LSQ		RCBD		LSQ		RCBD		LSQ	
	Kg/ha	RK	Kg/ha	RK	cm	RK	cm	RK	%	RK	%	RK	g	RK	g	RK	score	RK	score	RK
Essex	1794	11	1768	13	58	20	57	20	4.90	10	4.92	5	13.2	24	13.1	24	1.8	8	1.8	8
Forrest	1719	15	1794	10	74	10	75	10	4.72	23	4.76	23	12.1	25	12.1	25	1.8	8	1.8	8
K77-46-62	1865	6	1826	8	64	15	64	15	4.95	4	4.94	4	15.8	8	15.9	8	2.3	20	2.3	21
K77-46-19	1716	17	1747	15	73	11	73	11	4.82	16	4.87	13	16.8	4	16.6	4	1.6	2	1.7	4
K77-46-23	1690	19	1636	20	48	25	48	25	4.72	23	4.81	20	15.7	10	15.8	10	2.9	25	3.0	25
K77-46-40	1868	4	1852	4	75	9	76	8	4.89	11	4.87	13	15.5	12	15.5	13	2.7	23	2.7	23
K77-46-42	1707	18	1730	17	88	1	84	1	4.92	8	4.89	11	17.3	2	17.2	2	1.6	2	1.6	1
K77-46-45	1632	21	1562	23	54	23	54	23	4.73	21	4.70	24	15.4	13	15.5	13	2.1	15	2.1	15
K77-46-78	1549	24	1566	22	61	17	61	17	4.89	11	4.90	8	15.9	7	15.9	8	2.1	15	2.1	15
K77-50-09	1478	25	1497	25	59	19	59	19	4.92	6	4.89	11	14.6	18	14.6	18	2.7	23	2.8	24
K77-50-33	1720	15	1755	14	69	13	69	13	4.92	6	4.90	8	13.4	23	13.4	23	2.1	15	2.0	13
K77-50-53	1944	1	1946	1	80	3	79	4	4.98	2	4.96	2	15.1	17	15.0	17	1.7	4	1.7	4
K77-50-59	1752	12	1787	11	56	21	56	21	4.93	5	4.91	6	15.2	15	15.1	16	2.4	22	2.4	22
K77-50-63	1875	3	1860	3	77	6	77	6	4.91	9	4.81	20	13.9	22	14.0	21	2.2	10	2.2	19
K77-50-73	1850	7	1835	6	76	8	76	8	4.81	18	4.90	8	15.6	11	15.6	11	1.7	4	1.7	4
K77-63-44	1804	9	1747	15	62	16	61	17	4.80	19	4.83	17	14.1	21	14.0	21	1.8	8	1.8	8
K77-63-50	1867	5	1852	4	80	3	81	3	4.71	25	4.85	16	14.4	20	14.4	20	1.8	8	1.9	11
K77-63-67	1588	22	1626	21	55	22	55	22	4.73	21	4.69	25	15.4	13	15.5	13	1.9	12	1.9	11
K77-63-76	1577	23	1561	24	53	24	53	24	4.86	14	4.90	8	17.0	3	17.1	3	2.2	18	2.2	19
K77-63-84	1680	20	1726	18	70	12	70	12	4.82	16	4.83	17	16.0	6	16.1	6	2.1	15	2.1	15
K77-63-87	1821	8	1799	9	79	5	78	5	4.80	19	4.77	22	15.1	16	15.2	15	2.3	20	2.2	19
K77-66-03	1742	13	1779	12	61	18	61	17	4.82	16	4.86	15	15.8	8	16.0	7	1.8	8	1.8	8
K77-66-32	1729	14	1699	19	66	14	67	14	4.96	3	4.99	1	18.3	1	18.2	1	1.8	8	1.8	8
K77-66-42	1876	2	1863	2	77	6	77	6	4.87	13	4.81	20	16.5	5	16.6	4	2.1	15	2.1	15
K77-66-50	1807	9	1829	7	84	2	84	1	5.02	1	4.95	3	14.5	19	14.5	19	1.6	2	1.6	1
LSD(.05)	243		203		5		5		.21		.19		.8		.8		.8		.9	
MEAN	1746		1746		68		68		4.84		4.48		15.3		15.3		2.0		2.0	
P-Value																				
Line (L)	.0115		.0010		.0001		.0001		.0021		.0122		.0001		.0001		.1084		.1084	
L x ENV‡	.0050		.0100		.0051		.0600		.6477		.1759		.0050		.0024		.0001		.0001	
RANK CORR†		.95				.99				.80				.99				.99		

†Spearman correlation between the ranking of the means in the two types of design.
‡ENV=environment.

Table 16. Comparison of genotypic and interaction components of variance as obtained by RCBD analysis and as obtained by lattice square (LSQ) analysis for several plant traits.

Component of Variance	Plant traits									
	Seed yield		Plant height		Seed weight		Seed quality		Leaf nitogen	
	RCBD	LSQ	RCBD	LSQ	RCBD	LSQ	RCBD	LSQ	RCBD	LSQ
Genotype (Gen)	101,533	114,805	1375	1370	16.25	16.20	.42	.44	.095	.054
Gen x environment	44,405	38,594	17	12	.39	.40	.53	.53	-.005	.010

weight, and seed qualitiy were minimal.

The use of the LSQ design would, theretore, provide a better estimate of genetic components of variance in breeding trials combined over years and locations than the RCBD, and would provide more information to a breeder in selecting lines for wide adaptability.

CONCLUSIONS

Substantial gains in precision may b realized from the use of the lattice square design (LSQ) over the RCBD in soybean breeding trials, particularly for quantitative plant traits, such as seed yield, which are more influenced by field heterogeneity than more qualitative plant traits, such as plant height. Plant traits which are not likely to be influenced by field heterogeneity should be analyzed by method of randomized blocks to avoid inefficiencies which could occur with the use of the LSQ design.

The ability of the lattice square design to control the influence of field heterogeneity in two directions is a desirable property in soybean breeding trials, as the direction in which major variablity lies can not be predicted before hand. Major variablity is also often lain in two directions. In these situations the LSQ design achieves its maximum efficiency.

When gains in precision are realized from the use of the LSQ design, better estimates of genotypic means are obtained than that of the RCBD. Therefore, a breeder would have more confidence in selecting superior lines when using the lattice square design. When genotypic means, as obtained by LSQ analysis, are analyzed over a number of environments, a better estimate of genotype x environment interaction is obtained than with the RCBD analysis. This would aid a breeder in selecting superior lines over a number of locations and years.

The use of a lattice square design, once incorporated into a breeding program, would be no more time consuming to use than the RCBD. Under fixed resources the use of the LSQ design would provide more information than would be obtained from a RCBD and genetic gain should be improved.

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FACTORS AFFECTING SELECTION OF DOUBLE-CROP SOYBEAN GENOTYPES

by

DEXTER EGGERS

B.S., Kansas State University, 1981

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY

Manhattan, Kansas

1985

Twenty-five randomly chosen determinate and indeterminate soybean [*Glycine max* (L.) Merr.] lines were grown in two tillage treatments (wheat straw vs. fallow) over two years (1982, 1983) to determine the influence of wheat residue and stem termination on soybean double-crop performance and to assess the magitude of genotype x production system interactions in double-crop cultivar development. Seed yield was significantly lower in wheat residue environments (1820 Kg/ha) than fallow environments (1930 Kg/ha). (6%). Lower yields in these environments were probably more a result of soil physical and chemical conditions than phytotoxicity associated with wheat straw.

Genotypic variation for seed yield was masked by significant genotype x tillage treatment and genotye x environment interactions. The magnitude of the genotype x tillage treatment interaction indicated that the development of double-crop cultivars would be expedited by the testing and selection of lines in wheat residue environments.

Indeterminate lines outyielded determinate lines by 11%. Indeterminates showed only a 1% reduction in yield in wheat residue environments, while determinates suffered a 9% reduction. Indeterminate stem growth should improve the yield and stability of cultivars adapted to double-crop production in southeastern Kansas.

Cold water extracts derived from wheat straw stimulated soybean seedling growth when applied to pots in the greenhouse. Seedling growth and percent leaf nitrogen were substantially reduced, however, when seedlings were grown in pots mixed with wheat straw. Therefore, nitrogen availability is probably a more

important factor limiting the growth of soybeans in soybean double-crop production than the phytotoxicity of compounds leached from wheat straw .

A greenhouse evaluation was not effective in identifying lines tolerant to the effects of wheat straw. Dry matter production, plant height, and percent leaf nitrogen of seedlings were significantly reduced (13, 41, and 46%, respectively) among 25 lines evaluated. While the relative reduction for these traits differed among lines, plant responses in the greenhouse were not correlated to performance in the field.

The sub-plot treatments (genotypes) were arranged in a lattice square design (LSQ). This provided a comparison of the relative efficiency of a LSQ design to a randomized complete block design (RCBD) in several environments. Gains in precision of the LSQ over the RCBD averaged 40% for seed yield and 45% for percent leaf nitrogen. The effects of LSQ analysis were minimal for plant height, 100 seed weight, and seed quality, as these traits are more qualitive and less influenced by field heterogeneity. The use of a LSQ design would provide a better estimate of genotypic means than the RCBD and would give a breeder more confidence in selecting superior lines.