8-1987

Breeding soybean (Glycine max. L. Merr) varieties for single- versus double-crop production systems

Donald McLean Panter

To the Graduate Council:

I am submitting herewith a thesis written by Donald McLean Panter entitled "Breeding soybean (Glycine max. L. Merr) varieties for single- versus double-crop production systems." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

Fred L. Allen, Major Professor

We have read this thesis and recommend its acceptance:

Dennis West, Vernon Reich

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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To the Graduate Council:

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BREEDING SOYBEAN (*Glycine max.* L. Merr) VARIETIES FOR

SINGLE- VERSUS DOUBLE-CROP

PRODUCTION SYSTEMS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Donald McLean Panter, Jr.

August 1987

DEDICATION

This thesis is dedicated to my parents, Donald and Patricia Panter. With their love, guidance, and encouragement, anything would is possible.

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ABSTRACT

Soybeans [Glycine max. (L.) Merr.] are grown throughout the southeastern United States as both a single crop and as a second crop following small grains. Varieties currently grown in both systems were developed under conventional, mono-crop conditions. Concern over the development of current varieties has prompted researchers to question if these varieties are best suited for double-crop production or if new varieties should be developed which are specifically adapted for double-cropping.

Twenty-five determinate and 25 indeterminate F_4-derived breeding lines were evaluated for seed yield in conventional (tilled seedbed, optimum planting date, wide rows) and double-crop (wheat stubble seedbed, mid-June planting date, narrow rows) nursery environments to determine: 1) if relative yield of lines was similar in the two systems, and 2) if indeterminate lines were higher yielding than determinate lines under double-crop conditions. The tests were conducted at 26 location/year combinations in 1982-1986.

The 50 lines were separated into two groups based on overall means from the 26 combinations: 1) a superior group consisting of 17 lines which yielded above the overall mean in both conventional and double-crop nursery environments, and 2) a non-superior group consisting of all other lines. Genotype X nursery environment interactions were significant for both the superior and non-superior groups, but the magnitude of interaction was twice as great for the non-superior group. Stability analysis showed that the superior group had significantly higher mean regression values than the non-superior group in conventional tests, but there was no difference in double-crop tests. Selection of the top lines based on means from combinations of one, two, three, and four conventional tests in 1985, and combinations of one, two, three, and four double-crop tests in 1985, each produced up to 65% of the superior lines. The best breeding line was selected in every case. Mean yield differences were not significant between growth types in conventional tests, but determinates were significantly higher yielding than indeterminates in double-crop tests. The results from this study indicate there is no immediate need to maintain separate selection nurseries to enhance the development of soybean varieties adapted for double-crop production systems.

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CHAPTER I

INTRODUCTION

Soybeans [Glycine max (L.) Merr.] are grown throughout the southeastern United States as both a single crop and as a second crop following small grains in double-crop systems. Single-crop soybeans are generally planted in May to mid-June and are grown at row spacings of 75 to 100 cm. Double-crop soybeans are generally planted into small grain stubble in June to July and are grown at narrow row spacings of 40 to 60 cm to maximize seed yield and enhance competition against weeds where mechanical cultivation is not possible.

Growing soybeans in a double-crop system has become more and more popular and has several advantages over a single-crop system: 1) the ability to produce two crops in one season, 2) double-crop no-till soybean production requires less labor than conventional production thus permitting expansion of operation or a reduction of hired labor (20), 3) a no-till system has been estimated to reduce soil erosion by one third the rate under conventional tillage single-crop systems in Tennessee (20), and has been shown to decrease soil erosion in Mississippi from 19.6 t ha^{-1} under conventional tillage to only 0.6 t ha^{-1} under a double-crop, no-till system (23), and 4) the ability to produce yields comparable to those attained when producing full season soybeans (16).

There are some disadvantages to producing soybeans in a double-crop system. Until recently, the lack of effective herbicides to control weeds in a no-till system presented a serious problem to double-crop soybean producers. Early workers (14,24) predicted that if more effective and cheaper herbicides were available, soybean yields could be maximized in systems where narrow rows and/or a stubble crop prevented mechanical cultivation. Since the development of new herbicides effective for use in a no-till system, weed control is no longer the serious problem it once was in double-crop soybean production.

Another problem is the phytotoxic effect of the straw from the previous crop. Collins and Caviness (11) observed that wheat straw residues allowed to decompose for less than two weeks retarded top growth of soybeans. However, no yield reductions due to phytotoxic effects were reported. Cochran et al. (10) found that water extracts from straw of wheat and barley produced a phytotoxic effect on the growth of roots of wheat seedlings. These toxins were prevalent after conditions became favorable for microbial growth. It was observed that toxin production from these residues was irregular and was generally preceded by wet weather with air temperatures above freezing but below 15°C. Guenzi and McCalla (18) found that water extracts from wheat and oat straw contained water-soluble substances that inhibited the germination and growth of sorghum, corn, and wheat. In a later study, Guenzi et al. (19) observed that phytotoxic effects of wheat straw water extracts varied with different varieties. They also noted that the toxicity of aqueous extracts of wheat and oat straw remained about the same through the first four weeks. Essentially all toxic components from the water extract had disappeared after eight weeks of decomposition and, in some cases, there was a slight stimulative effect of the residues. Although these phytotoxic substances affect all plants in general, there is a possibility that some plant genotypes are less inhibited by residual toxins than others.

Another issue that double-crop soybean producers face is the question of varieties which are best adapted for use in a double-crop system. The varieties currently grown in double-crop systems were developed for single-crop environments and considerable interest has been expressed in varieties specifically adapted to double-crop environments.

Results from research conducted in 1971 prompted Peters et al. (25) to contend that the soybean varieties selected for maximum production in single-cropping may not be well suited for double-cropping. Seven varieties were planted on various dates from late May to early July in East Tennessee and yield was recorded. Of the seven varieties chosen for the study, 'Kent' was shown to produce high yield, mature early, and was not greatly affected by delayed planting dates. It was concluded that 'Kent' most closely fit the need for a variety suited to a double-crop system when compared to the others varieties in the study. Peters suggested that "soybean breeding efforts could profitably be oriented in working toward similar types with improved shatter resistance, seed quality, and grain yield."

Today, more soybean breeders are concentrating efforts on the development of varieties specifically adapted for double-crop systems. Questions remain concerning what growth types should be selected for adaptability and production in double-crop systems. There is evidence from Georgia (5) that suggests indeterminate growth types have some advantage over determinate growth types since indeterminates continue vegetative growth after flowering and could attain more vegetative tissue over the shorter growing season.

Another question is in what environment should selection nurseries be maintained for maximum progress in selecting varieties for double-crop production. More research from Georgia (7) resulted in the suggestion that selection nurseries should be maintained in a late planted, narrow row environment to achieve maximum progress. Research pertaining to these questions could provide useful information and facilitate development of soybean varieties specifically adapted to double-crop production systems.

The objectives of this study are to determine:

1. if selection for superior soybean strains adapted specifically for double-crop systems should be made in double-crop nursery environments or if selection of the same superior types can be made in conventional nursery environments; and

2. if indeterminate soybean plant types are superior in performance to determinate plant types in double-crop systems following wheat.

CHAPTER II

LITERATURE REVIEW

I. ROW SPACING STUDIES

As early as 1960, workers had investigated the effects of row spacing on yield of soybeans. Pendleton et al. (24) conducted a study to determine the yield responses of four varieties, 'Chippewa', 'Clark', 'Harosoy', and 'Shelby', to varying row widths from eight to 40 inches. The results indicated that different varieties responded to row spacing in much the same manner. All varieties yielded the highest at 24 inch row spacings and the lowest at 40 inch row spacings. Lehman and Lambert (21) also conducted a study to determine the responses of the variety 'Blackhawk' and ancestral line 'Mandarin' to row spacings of 20 and 40 inches. Their conclusions agreed with Pendleton et al. that seed yields tended to be higher at narrow row spacings.

In 1965, Cooper and Lambert (12) observed that the seed yields of the varieties 'Acme', 'Chippewa', and 'Merit' were consistently higher in narrow spaced rows (20-24 inch) than in wide spaced rows (30 inch) in Minnesota. They also surmised that the magnitude of the yield increases from narrow rows was great enough to be of economic importance.

Other workers have reported varietal differences in response to narrow row spacing. Using five adapted varieties plus two isolines of the variety 'Clark', Cooper (13) found highly significant variety x row spacing interactions for seed yield. Cooper (14) later observed that when seeding rate was low enough to prevent lodging, yield advantages of 10 to 20% could be obtained from planting in 17 cm rows compared to 50 or 75 cm rows. It was also noted that earlier maturing varieties tended to be more responsive to 17 cm rows than later maturing varieties. Carter and Boerma (7) observed significant row spacing x genotype interactions for seed yield in an experiment using nine Southern varieties and one experimental breeding line planted at narrow (38 cm) and wide (96 cm) row spacings. Boquet et al. (6) noted significantly higher yields in five Southern varieties grown at 25 and 50 cm row spacing as compared to 100 cm row spacing and that differences among varieties in degree of response to row spacing were apparent.

II. PLANTING DATE STUDIES

Pendleton et al. (24) conducted research in 1960 to determine the yield response to varying planting dates from May 10 to June 23 at row spacings from eight to 40 inches of four Northern soybean varieties. They reported that varieties responded similarly to planting date regardless of row spacing. Yields were highest at May planting dates and lowest at June planting dates. More recently, workers in both the South and North (6,7,13) reported similar results that indicated planting dates before May 1 or after June 1 tended to result in decreased seed yields.

Varietal differences in response to planting dates have also been reported. Carter and Boerma (7) reported significant genotype x planting date interactions, and Boquet et al. (6) found variety x planting date interactions to be highly significant in each year of a four year study. Cooper (13) observed highly significant variety x planting date interactions in tests using five Northern varieties and two isolines of the variety 'Clark'.

In a study using six Southern varieties and one experimental breeding line, Board (4) reported yield components associated with soybean seed yield reductions at non-optimal planting dates differed with planting date and genotype. Seed yield reductions of all genotypes at the mid-June planting date were associated with decreased branch number which was related to fewer branch nodes and fertile nodes. Consequently, fewer branch pods and seeds were produced which resulted in lower seed yield. Reduced branch nodes and proportion of branch nodes becoming fertile were associated with seed yield reduction at early April planting date. Fewer fertile branch nodes were produced which was associated with fewer branch pod and seed numbers, resulting in lower seed yield. These results indicate that a possible selection criterion for late-planted soybeans might be increased branch production.

III. GROWTH TYPE STUDIES

Bernard (3) confirmed that the inheritance of the common determinate (abruptly terminated) stem type (dt_1) versus indeterminate (tapered) stem type (Dt_1) in soybeans was monogenic. He reported that the heterozygote Dt_1dt_1 showed an intermediate or semi-determinate phenotype in the genetic backgrounds studied. A stem type resembling the heterozygote was found in a few true breeding varieties and was shown to be controlled by a single dominant gene designated as Dt_2. Crosses between the heterozygote (Dt_1dt_1) and varieties with the similar phenotype produced F_2 ratios of 1 indeterminate: 11 semi-determinate: 4 determinate, the expected ratio for independent segregation with dt_1 epistatic to Dt_2dt_2.

Research concerning yield stability of indeterminate stem types versus determinate stem types has produced conflicting results. Thseng and Huang (26) studied six determinate and four indeterminate varieties of soybeans grown in three crop seasons (spring, summer, and fall) at four planting densities and observed that for agronomic traits, indeterminate types were more adaptable to seasonal variation than determinate types. They reported that the yield stability and average yield in most indeterminate varieties were greater than determinate varieties. Beaver and Johnson (1) conducted a yield stability analysis on eight determinate, three semi-determinate, and eight indeterminate soybean genotypes ranging in maturity from Group II to IV at eight location/year combinations. Their results indicated that, in general, determinate and indeterminate genotypes possessed a similar yield response to environments of varying levels of productivity.

Foley (17) and others evaluated 21 determinate and 21 indeterminate soybean lines, randomly selected from each of three crosses, at three locations in Minnesota in 1982 to compare the agronomic and developmental characteristics of each growth type. Their results indicated the stem termination types did not differ significantly for yield. However, determinates did tend to lodge less than indeterminates and they concluded that the determinate stem termination type could be potentially useful for improving yield and lodging resistance in soybeans for the northern USA.

Row spacing studies comparing yield response of indeterminate genotypes versus determinate genotypes have produced consistent results. Chang et al. (9) compared yield responses of near-isogenic, F_4 and F_5-derived semi-determinate and indeterminate lines from three crosses at row spacings of 35 cm and 70 cm. They reported that stem termination type had no effect on seed yield, regardless of genetic background and row spacing and hypothesized that morphological changes induced by semi-determinateness, principally shorter plant height, would make them better fitted than indeterminates to narrow row culture. Similarly, Wilcox (27) evaluated 40 semi-determinate and 40 indeterminate soybean lines from three crosses at row spacings of 0.5 and 1.0 m. He reported that the interactions of plant type x row spacing were not significant and that both the semi-determinate and indeterminate lines responded similarly to the two row spacings used in the study. Beaver and

Johnson (2) observed seed yield increases of comparable magnitude in determinate varieties ('Gnome' and 'Elf') and indeterminate varieties ('Beeson' and 'Williams') when row spacing was decreased from 80 cm to 50 cm.

Differences in yield response to planting date of determinate versus indeterminate genotypes have been reported. Beaver and Johnson (2) observed that seed yield in central Illinois decreased an average of 33% as planting date was delayed from early May to early June. Seed yield of indeterminate varieties declined steadily after the early May planting date, whereas, seed yield of determinate varieties did not decrease until planting date was delayed past early June. They also note that this study was the first case where a differential response in seed yield to planting date was associated with a difference in growth habit.

IV. VARIETY DEVELOPMENT AND ADAPTATION

Results from various studies have prompted researchers to suggest that soybeans varieties should be selected for special adaptation to narrow rows and/or varying planting dates.

Boquet et al. (6) stated that their results from a row spacing/planting date study with five Southern determinate varieties indicated that significantly higher yields are possible with current determinate varieties when both row spacing and planting date are selected for individual varieties. Carter and Boerma (7) observed significant genotype x planting date, genotype x row spacing, and genotype x planting date x row spacing interactions for yield. In comparing yield of the 10 genotypes in the study, they found that the two highest yielding genotypes in early planting date-wide row environments ranked ninth and tenth in the late planting date-narrow row environment. From these data, they conclude that because of the magnitude of the interactions among genotypes, planting date, and row spacing for yield, development and testing of varieties especially adapted for double cropping should be practiced in a late-planted, narrow-row nursery environments for maximum progress from selection.

The results of a study conducted by Metz et al. (22) concerning the relationships of soybean yield in narrow rows with leaflet, canopy, and developmental characters, indicated that small leaflet size and low leaflet mass in the late-maturity groups were closely associated with high yield. They suggest that in breeding soybeans for narrow rows, selection for an open canopy with small leaflets may be an effective tool for preliminary screening of lines.

Recently, two varieties have been released with specific adaptation for narrow rows and/or varying planting dates. 'Duocrop', released from Georgia in 1982 (5),

> "... is specifically adapted to planting after 20 June where lack of sufficient vegetative growth is often a barrier to efficient mechanical harvest and higher seed yields of determinate cultivars. ...It has indeterminate growth habit which allows increased vegetative growth after the onset of flowering when compared to cultivars with determinate growth habit. ...When planted prior to 20 June, it will produce excessive vegetative growth which can result in severe lodging and yield reduction. Thus, it is specifically adapted to planting after 20 June."

Caviness et al. (8) released the variety 'Narow' in 1983 which is described as:

> "... a short stature, low lodging, early variety (group V maturity) especially adapted for planting in narrow rows at recommended planting dates. It should be planted in Arkansas before June 5. Generally, plants will be too short for efficient combining and production of high yields if planted later or if grown under stress conditions."

Other research has shown that development of new varieties adapted for double-crop production is unnecessary. Elmore (16) conducted a field study to compare six soybean cultivars of different maturities and growth habits in three tillage systems: double-disk, single-disk, and no-till. Results from this study indicated that tillage system did not affect yield, and cultivars responded similarly to tillage systems. The best yielding cultivars in tilled systems were also best yielding in the no-till system and he concluded that there was no immediate need for cultivar performance testing in different tillage systems.

CHAPTER III

MATERIALS AND METHODS

Fifty F_4-derived breeding lines from 18 different pedigrees falling into maturity groups IV, V, and VI were chosen as entries for this study. The lines were selections from crosses between determinate and indeterminate parents. Progeny were advanced through single seed descent in the F_2 and F_3 generations. At the F_4 generation, single plants were selected and became whole rows in the F_5 generation. At that point, at least one pair of determinate and indeterminate lines (sharing 93.75% of their genes) were selected within the 18 pedigrees as entries for this study. Two determinate check varieties ('Forrest' and 'Essex') were also included in the study to bring the total number of entries in the test to 52 (Table A-1, Appendix).

The 52 entries were grown in one row plots (1982 through 1984) or three row plots (1985 and 1986), 6 m long, in a randomized complete block design with three replications in each of two different types of yield test nurseries. One type yield test was considered a "conventional" nursery environment. Conventional nurseries in 1982 through 1986 were planted into tilled soil (plow, disk, harrow) in late April to early May at 90 cm row spacing. The seeding rate was 33 seed per linear meter. Fertilizer was applied according to soil test recommendations and TREFLAN was applied at a rate of 2.34 l ha^{-1} as a preplant treatment. Weeds were controlled both mechanically and chemically as needed.

The second type yield test was considered a "double-crop" nursery environment. Plots consisted of one row, 6 m long, 90 cm row spacing, and a seeding rate of 33 seed per linear meter in 1982 and 1983; and three rows, 6 m long, 50 cm row spacing, and a seeding rate of 23 seed per linear meter in 1984 through 1986. Double-crop nurseries were planted into standing wheat stubble in early to mid-June. Assuming a germination rate of 80% that of the conventional nursery, the number of plants per hectare for the double-crop nursery was comparable to the number of plants per hectare of the conventional nursery. Fertilizer was applied according to soil test recommendations at the time the wheat was planted. Weed control consisted of the application of 2.34 l ha^{-1} PARAQUAT + 1/2% surfactant + 2.92 l ha^{-1} DUAL. As needed, 1.17 l ha^{-1} each of BASAGRAN + BLAZER was applied as an over-the-top treatment for broadleaf weed control and 2.34 l ha^{-1} POAST as an over-the-top treatment for grass control.

The experiments were grown at two locations each year in 1982 through 1984 and at seven locations each year in 1985 and 1986 (Table A-2, Appendix). These locations represent the diverse edaphic and climatic conditions which exist across Tennessee and are comparable to those in adjacent states. Due to severe drought in 1983 and 1986, several plots were discarded in various tests and the measurements which were recorded are not included in these results.

At maturity, plant height (mm), lodging score (Score 1-5), and maturity date (days after August 31) were recorded. Lodging was scored on the USDA scale of one to five where: 1=almost all plants erect; 2=either all plants leaning slightly, or a few plants prostrate; 3=either all plants leaning moderately, or 25 to 50% of the plants prostrate; 4=either all plants leaning considerably, or 50 to 80% of the plants prostrate; and 5=all plants prostrate. In conventional tests, the center row was trimmed to 4.9 m and was harvested for seed yield with a plot combine. In double-crop tests, the three rows were trimmed to 4.9 m and were harvested for seed yield with a plot combine. All yields were adjusted to 13% moisture.

The statistical model for analysis of variance in this study was:

$$Y_{ijkl} = M + L_i + N_j + R_k(L_i) + G_l + LN_{ij} + LG_{il} + NG_{jl} + LNG_{ijl} + E_{ijkl}$$

where:

Y_{ijkl} = Yield of the l^{th} Genotype at the i^{th} Location, the j^{th} Nursery Environment, and the k^{th} Replication within the i^{th} Location

M = Mean Yield

L_i = the effect of the i^{th} Location

N_j = the effect of the j^{th} Nursery Environment

$R_k(L_i)$ = the effect of the k^{th} Replication within the i^{th} Location

G_l = the effect of the l^{th} Genotype

LN_{ij} = the effect of the interaction of the i^{th} Location with the j^{th} Nursery Environment

LG_{il} = the effect of the interaction of the i^{th} Location with the l^{th} Genotype

NG_{jl} = the effect of the interaction of the j^{th} Nursery Environment with the l^{th} Genotype

LNG_{ijl} = the effect of the interaction among the i^{th} Location, the j^{th} Nursery Environment, and the l^{th} Genotype

E_{ijkl} = the error associated with the l^{th} Genotype at the i^{th} Location, the j^{th} Nursery Environment, and the k^{th} Replication within the i^{th} Location

Regression analysis was used to determine if relationships existed between conventional and double-crop yield of determinate and indeterminate growth types, and a t test was performed to determine if mean yields of determinate and indeterminate growth types was different in either conventional or double-crop nursery environments. Regression analysis was also used to determine if relationships existed between yield and height, maturity, and lodging. A stability analysis was conducted using the method of Eberhart and Russell (15) and t tests were used to ascertain 1) if superior lines had different regression values than non-superior lines, and 2) if the mean difference between double-crop and conventional regression values was different from zero.

CHAPTER IV

RESULTS AND DISCUSSION

I. ANALYSIS OF VARIANCE

Severe drought at planting in 1986 resulted in inadequate stands of all yield tests under double-crop productions systems; therefore, only data from six locations in 1985 were used to perform an analysis of variance to determine the effects of location, nursery environment, genotype, and interactions among these effects on seed yield.

Variation in seed yield due to location and nursery environment was not significant. As expected, there were significant differences in seed yield among breeding lines. Location X nursery environment, genotype X location, and genotype X nursery environment interactions were significant (Table 1).

These results indicate that genotypes respond differently under different environmental and cultural conditions. The scatter diagram in Figure 1 shows double-crop yield plotted against conventional yield. Vertical and horizontal lines illustrate the overall mean yield under each nursery environment. The upper right-hand quadrant (hereafter referred to as the superior quadrant) represents superior breeding lines which have high yield in both nursery environments. Selection of the top 10 lines (20% selection intensity) in conventional nursery environments would result in eight lines falling

Table 1. Analysis of variance of seed yield using six locations, two nursery environments (double-crop and conventional), and 52 genotypes (50 breeding lines plus two check varieties) in 1985.

Source	df	Mean Square	F Value†
Location (LOC)	5	47668951	3.45
Nursery Environment (NE)	1	12992122	0.81
LOC X NE	5	15564395	6.47**
Genotype (G)	51	1093727	1.51*
G X LOC	255	201812	1.19**
G X NE	51	686579	4.15**
G X NE X LOC	255	165583	1.91**
Replication	12	524657	0.23

†*,** Significant at $P \leq 0.05$ and 0.01, respectively

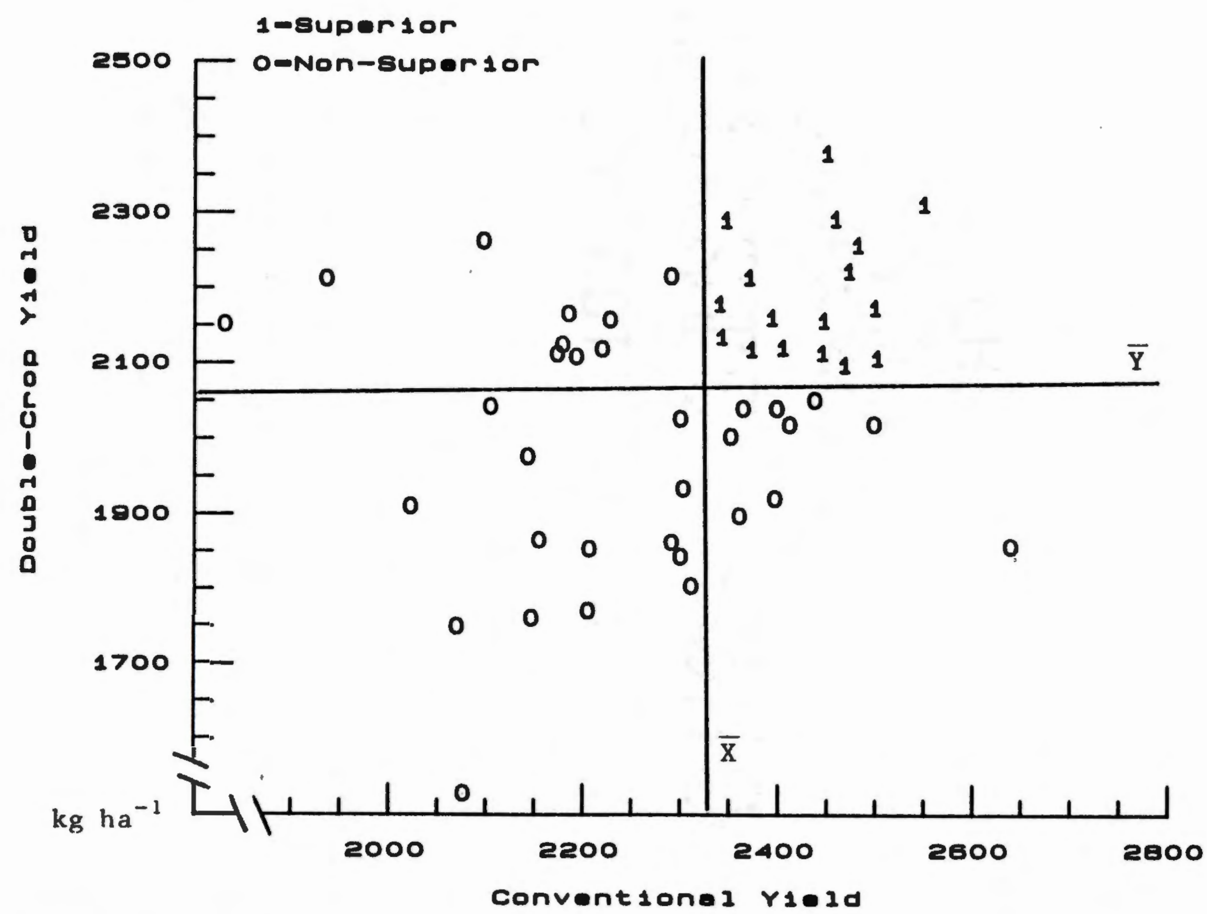


Figure 1. Scatter diagram of means for the superior and non-superior lines in double-crop versus conventional yield test nurseries (1982-1986).

into the superior quadrant. Likewise, selection of the top 10 lines in double-crop nursery environments would result in seven lines falling into the superior quadrant. The ability to select such a large percentage of the superior lines from either conventional or double-crop nursery environments suggested that variation in the genotype X nursery environment interaction was mainly due to the non-superior breeding lines.

An analysis of variance was performed to determine if there were differences in the magnitudes of the genotype X nursery environment interactions between the breeding lines in the superior and non-superior groups (Table 2). Results showed that the group X nursery environment interaction was not significant indicating that the two groups responded to conventional and double-crop nursery environments similarly. However, genotypes within both the superior and non-superior groups did interact significantly with nursery environment ($P \leq 0.01$). By partitioning the sums of squares and degrees of freedom of the genotypes within group X nursery environment interaction into superior and non-superior group components, the ratio of the non-superior group variance with the error variance was found to be greater than the ratio of the superior group variance with the error variance (5.00 versus 2.41, respectively). These ratios indicate that the non-superior group contributed twice as much as the superior group to the variation due to genotypes within group X nursery environment interaction.

Consequently, although genotype X nursery environment interactions are significant ($P \leq 0.01$), selection for the superior

Table 2. Analysis of variance of seed yield to determine the effects of group (superior and non-superior) X nursery environment (conventional and double-crop) and genotypes within group X nursery environment interactions.

Source	df	SS	MS	F Value†
Location (LOC)	5	238344758	47668952	
Group (GRP)	1	22072610	22072610	
LOC x GRP	5	2242029	448406	
Nursery Environment (NE)	1	12992123	12992123	
LOC X NE	5	77821976	15564395	
GRP X NE	1	106696	106696	0.18
LOC X GRP X NE	5	392999	78600	
Genotype within Group (G/GRP)	50	33707491	674150	
G/GRP X LOC	250	49220146	196881	
G/GRP X NE	50	34908833	698117	
Superior Genotypes X NE	16	6462166	403885	5.00**
Non-Superior Genotypes X NE	34	28446668	836667	2.41**
G/GRP X NE X LOC	250	41830655	167323	

†** Significant at $P \leq 0.01$

lines can be practiced under either nursery environment and will produce lines with superior performance under the other nursery environment.

From a soybean breeding standpoint, a breeder can select the superior lines based on performance in conventional yield test nurseries and expect that those lines will also be superior lines in double-crop production. The reverse is true also. Selection for superior lines based on performance in double-crop yield test nurseries should produce lines which are superior in conventional production as well. The advantage to utilizing double-crop nursery environments would be erosion control and moisture conservation, rather than improving the effectiveness of selection for soybean lines which are better adapted to double-cropping.

II. ANALYSIS OF DETERMINATE VERSUS INDETERMINATE GROWTH TYPE

Data from 6 conventional and 6 double-crop tests in 1985 were used to determine if there was a difference in performance between determinate (D) and indeterminate (I) growth types. The analyses were performed using means for each breeding line across all conventional and across all double-crop tests. Figure 2 shows a scatter plot of yields of growth types in double-crop yield versus conventional yield with the points coded as "D" or "I" to represent growth type.

Double-crop yield was regressed on conventional yield to determine if a relationship existed between conventional yield and

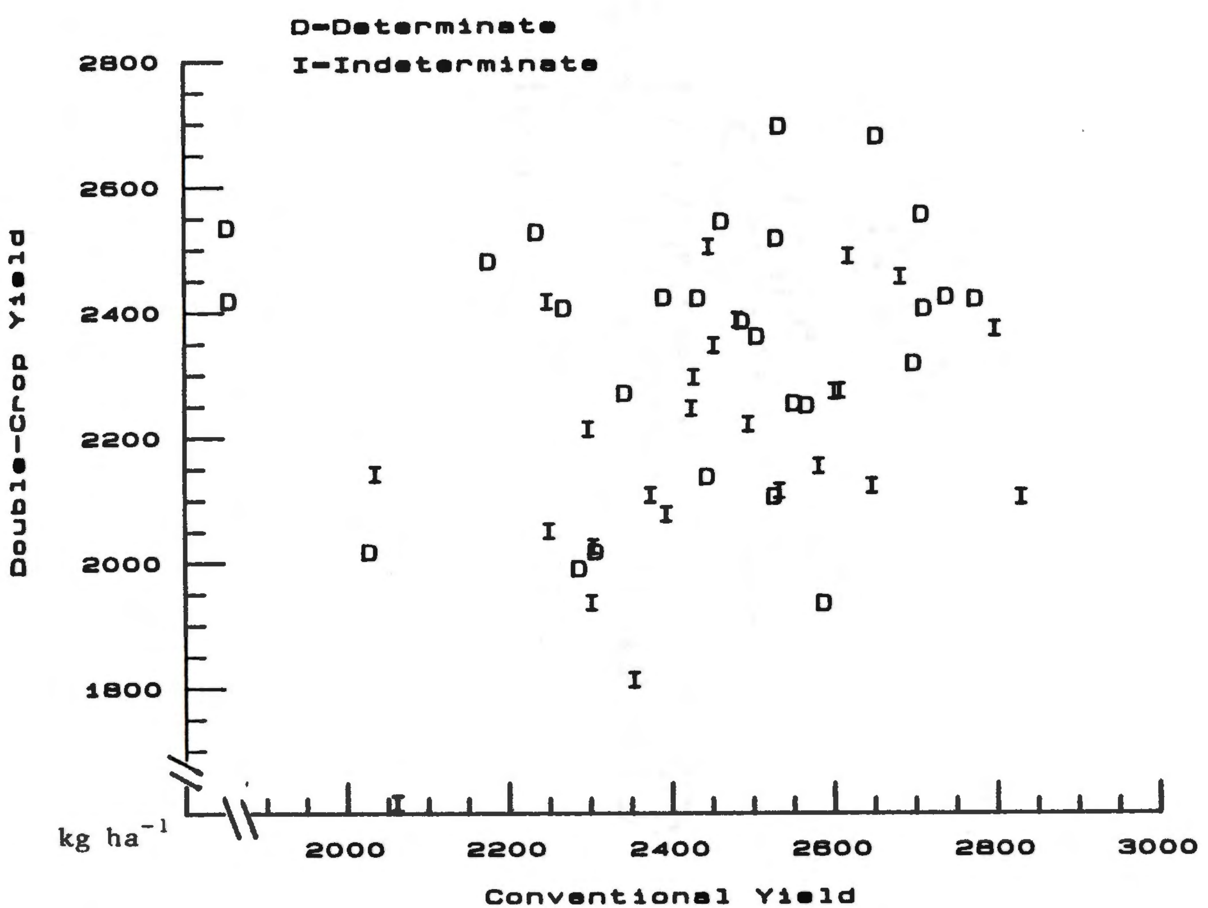


Figure 2. Scatter diagram of the mean yields of 25 determinate and 25 indeterminate breeding lines in double-crop versus conventional yield test nurseries (1985).

double-crop yield for each growth type. For determinate growth types, the slope ($b=0.09\pm0.17$) was not significantly different from zero ($P\leq0.05$), indicating that there was no relationship between conventional yield and double-crop yield. For indeterminate growth types, the slope ($b=0.50\pm0.19$) was significant ($P\leq0.05$) indicating that a relationship did exist. The regression lines for each growth type are presented in Figure 3. Results from this analysis indicate that double-crop yield of indeterminate growth types can be predicted from conventional yield, but double-crop yield of determinate growth types cannot be predicted from conventional yield.

A t test was performed to determine if the mean yield of determinate growth types was different from the mean yield of indeterminate growth types under either nursery environment (Table 3). The results indicate that there is a significant difference in the mean yield of determinate and indeterminate growth types in double-crop nursery environments but not in conventional environments.

The results from these analyses show that double-crop yield can be predicted from conventional yield data for indeterminate growth types more accurately than for determinate growth types. There is no clear yield advantage of one growth type over another under conventional nursery environments but determinate growth types, as a group, did yield higher in double-crop nursery environments than indeterminate types. When only considering the superior group, there was no relationship ($P\leq0.05$) between double-crop yield and

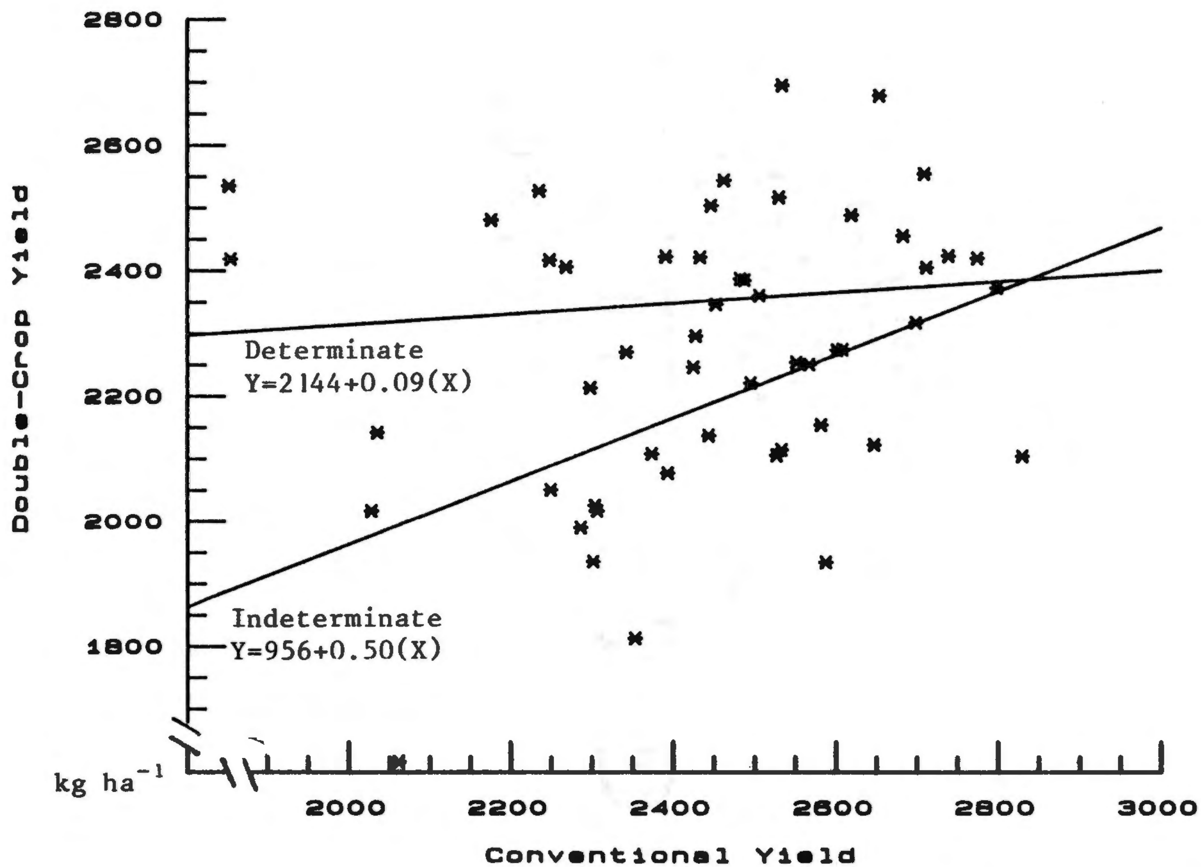


Figure 3. Least-squares regression line for the group of 25 determinate breeding lines and the group of 25 indeterminate breeding lines in double-crop versus conventional yield test nurseries (1985).

Table 3. Comparisons of the mean yield of determinate growth types with indeterminate growth types in conventional and double-crop nursery environments.

Nursery Environment	Determinate Group	Range	Indeterminate Group	Range	t Value†
	---------------	---------kg ha^{-1}	---------	---------------	
Conventional	2432±48	1853-2775	2449±40	2034-2829	-0.29
Double-Crop	2351±40	1934-2694	2190±42	1616-2503	2.79**

†** Significant at P≤0.01

conventional yield for either determinates or indeterminates ($b=-0.02\pm.32$ and $-0.11\pm.36$, respectively).

In terms of soybean breeding, these results indicate that the soybean breeder should not be overly concerned with selecting one growth type over another for genotypes adapted to conventional and double-crop environments. Selection of superior genotypes will produce both determinate and indeterminate growth types. The breeder might be able to gain effectiveness in predicting double-crop yield from conventional yield by selecting only indeterminate growth types, but would sacrifice the yielding ability of determinate growth types by selecting against them.

III. ANALYSIS OF OTHER AGRONOMIC CHARACTERISTICS

Four conventional environments in 1982 through 1985 and three double-crop environments in 1984 and 1985 were used to determine the relationships between yield and maturity, height, or lodging. The objective of these analyses was to ascertain whether selection for high yield was actually selection for extreme expression of one of the other measured traits in either the conventional or double-crop nursery environments.

Yield was regressed on each measured trait for conventional and double-crop nursery environments separately to determine the significance and magnitude of each relationship. The regression analysis was performed 1) using all 50 breeding lines in the test, and 2) using only the 17 breeding lines in the superior quadrant.

Table 4 shows the means and ranges for maturity, height, and lodging of all lines and the superior lines.

When regression analysis was performed on all lines in the test, results indicated a significant relationship between yield and each trait (Table 5). However, the magnitude of the relationships between yield and maturity, and between yield and height did not appear biologically significant. For example, an increase in one day until maturity resulted in an increase of only 12.31 kg ha^{-1} increase in yield in conventional environments and a loss of 7.10 kg ha^{-1} in double-crop environments. Lodging regression coefficients indicate a significant increase in yield as more lodging occurred. In each environment, lodging was scored visually on a scale of 1 (all plants erect) to 5 (all plants prostrate). Those lines which tended to yield more also tended to be scored higher for lodging. However, lodging was not a detrimental factor in any test and did not interfere with mechanical harvest. Therefore, the relationship that existed between yield and lodging was merely a prediction of a line's susceptibility to lodge and not an actual measure of lodging.

When only the lines in the superior group were used in the regression analysis, there was no relationship between yield and maturity or between yield and height in conventional environments. In double-crop environments, there was no relationship between yield and maturity, and the statistically significant relationship between yield and height appeared to be biologically insignificant. As with the previous analysis, lodging was not considered biologically significant even though relationships were statistically significant.

Table 4. Means and ranges for maturity, height, and lodging of all lines and the superior lines in selected conventional and double-crop nursery environments from 1982 through 1985.

	Maturity				Height				Lodging			
	Conventional		Double-Crop		Conventional		Double-Crop		Conventional		Double-Crop	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
	days†				mm				score‡			
All Lines	32	12-54	51	32-70	1049	457-1524	832	431-1270	2.5	1-5	2.3	1-5
Superior Lines	34	14-48	52	38-67	1046	660-1524	855	432-1270	2.5	1-5	2.3	1-5

† Days after August 31

‡ 1=all plants erect to 5=all plants prostrate

Table 5. Regression values for yield regressed on maturity, height, and lodging for all 50 breeding lines and only the 17 breeding lines in the superior group for conventional versus double-crop nursery environments.

50 Breeding Lines			
Dependent Trait	Independent Trait	Regression Value	
		Conventional	Double-Crop
Yield (kg ha^{-1})	Maturity (Days)	12.31*	-7.10*
Yield	Height (mm)	0.77**	1.95**
Yield	Lodging (Score 1-5)	173.63**	187.84**

17 Breeding Lines in Superior Group			
Dependent Trait	Independent Trait	Regression Value	
		Conventional	Double-Crop
Yield (kg ha^{-1})	Maturity (Days)	9.35	-11.85
Yield	Height (mm)	0.61	1.64**
Yield	Lodging (Score 1-5)	201.58**	225.79**

*,** Significant at $P \leq 0.05$ and 0.01, respectively

Selection for high yield was found not to be selection for extreme expression of another measured trait. A statistical relationship existed between yield and maturity and between yield and height under both conventional ($b=12.31^{*}$ and 0.77^{**}, respectively) and double-crop environments ($b=-7.10^{*}$ and 1.95^{**} respectively) when all breeding lines were considered. However, since the magnitudes of these relationships were small, they were deemed biologically insignificant. The relationship between yield and height was significant when only the breeding lines in the superior group were considered. This relationship was also considered biologically insignificant. Also, the measure for lodging reflected a line's potential to lodge rather than the effect of lodging itself since detrimental effects due to lodging were not observed. The relationship between yield and lodging was therefore considered negligible. Therefore, the soybean breeder does not need to select genotypes with special agronomic characteristics such as late maturity or increased plant height in order to attain superior yield performance in double-crop production systems. Although lodging was not a detrimental factor in this test, the breeder should consider selecting for resistance to lodging since other research has shown lodging to be a significant factor in reducing yields under any production system.

IV. SIMULATED SELECTION

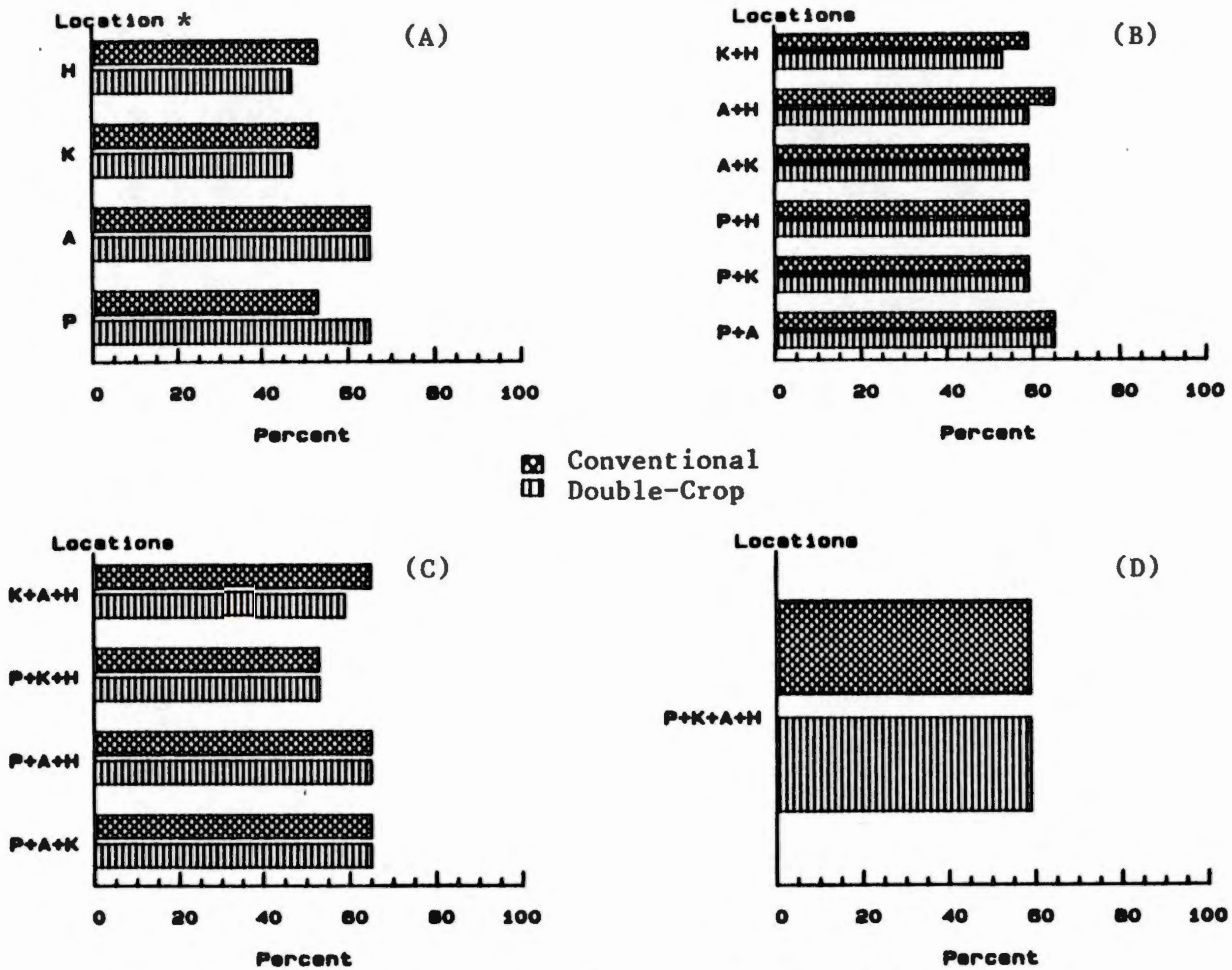
Of the 26 yield tests from 1982 through 1986 used in the analysis, 16 tests were grown in conventional nursery environments and 10 tests were grown in double-crop nursery environments. Overall mean yield for each breeding line was calculated separately for each nursery environment.

Overall conventional seed yield was plotted against overall double-crop seed yield for each breeding line (Figure 1, page 21). The graph was then divided into 4 quadrants; the two dividing lines being overall conventional mean yield across all breeding lines and tests and overall double-crop mean yield across all breeding lines and tests. The 17 breeding lines falling in the quadrant above both the conventional and double-crop means were considered the superior breeding lines in the test and were deemed the most desirable lines for selection.

Four tests from conventional nursery environments and four tests from double-crop nursery environments conducted in 1985 were chosen at random to combine in various combinations for the purpose of simulating selection for superior genotypes based on yield from those combinations. The four random tests from each nursery environment were combined in all combinations of one, two, three, and four tests and mean yield and rank were calculated for each of the 50 breeding lines for each of the combinations. The rationale behind selecting the superior breeding lines from these combinations of random locations was to simulate a plant breeder's method of yield testing at various locations within a diverse geographic area and selecting superior genotypes based on their mean yields from those locations. Counts were made to determine how many of the top 17 breeding lines based on the various combinations of the random tests were among: 1) the 17 lines falling in the superior quadrant (Figure 4), and 2) the top five of the 17 lines falling in the superior quadrant (Figure 5).

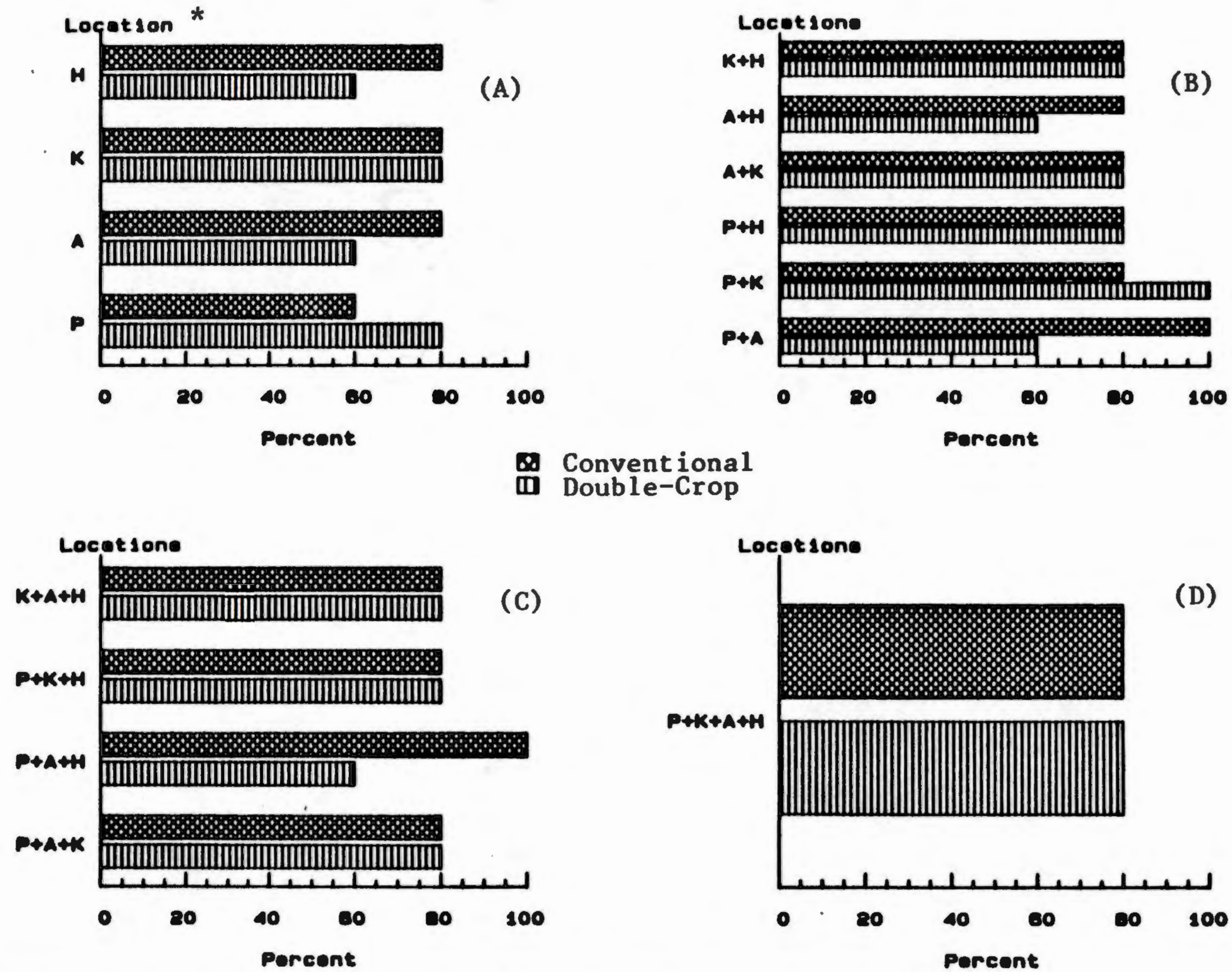
From the four random conventional tests in 1985, 53 to 65% of the 17 superior breeding lines would have been selected based on means calculated from only one test; 59 to 65% based on two tests; 53 to 65% based on three tests; and 59% based on all four tests. From the four random double-crop tests in 1985, 47 to 65% of the 17 superior breeding lines would have been selected based on means calculated from only one test; 53 to 65% based on two tests; 53 to 65% based on three tests; and 59% based on all four tests. In all cases, 60 to 100% of the top five breeding lines would have been selected based on mean yield of the various combinations. It is important to note that in every simulated selection made, the top breeding line overall (Tn82-192) would have been among the breeding lines selected based on mean yield for that combination.

These percentages indicate that selection based on yield in one or two tests in either conventional or double-crop nursery environments produces the majority of the superior breeding lines. As the number of tests were increased, the ability to substantially improve selection efficiency was not increased accordingly. Furthermore, selection based on yield in one or two tests, in either conventional or double-crop nursery environments, consistently



*P-Plateau, A-Ames Plantation, K-Knoxville, and H-Highland Rim

Figure 4. Simulated selection for the top 17 lines based on means from (A) one location, (B) two locations, (C) three locations, and (D) four locations in double-crop and conventional yield test nurseries.



*P-Plateau, A-Ames Plantation, K-Knoxville, H-Highland Rim

Figure 5. Simulated selection for the top five lines based on means from (A) one location, (B) two locations, (C) three locations, and (D) four locations in double-crop and conventional yield test nurseries.

produced the top five breeding lines and always produced the top breeding line. This ability to consistently select the most superior breeding lines indicates that superior breeding lines consistently outperform other lines across a variety of different environments.

The results from this analysis can have a direct impact on a soybean breeding program. Since it has been demonstrated that superior genotypes respond similarly in either conventional or double-crop environments, it would be unnecessary to expend the necessary resources to maintain separate conventional and double-crop nursery environments to select genotypes which are superior in both types of environments. Therefore, without having to actually test superior genotypes in double-crop environments, those genotypes selected for superior performance in conventional nursery environments can be expected to be among the superior genotypes in double-crop environments, and vice versa.

V. STABILITY ANALYSIS

Using data from the six locations in 1985, stability analyses were performed within each nursery environment (conventional and double-crop) to determine the relative yield response of each breeding line to varying environmental conditions. Using the regression technique of Eberhart and Russell (15), breeding line yield was regressed on mean test yield resulting in regression values and intercepts. Since a line must consistently perform above the test mean in order to be a superior line and since a line must consistently perform equal to or above the test mean across various environments in order to be stable, it was postulated that a line considered to be stable would also be a line with superior yield. If this hypothesis were correct, a soybean breeder's selection for yield stability would produce the superior yielding lines as well.

Lines with regression values of 1.0 or greater and relatively low deviations from regression were considered stable because their yields increased proportionally with mean test yield. Lines with either regression values less than 1.0, relatively high deviations from regression, or both, were considered unstable because their yields did not increase proportionally with mean test yield. Lines were separated into two groups: 1) those lines falling into the superior quadrant, and 2) all other lines. Regression values in the superior group were compared to regression values in the other group.

Of the 17 lines falling into the superior quadrant, 12 lines (71%) had regression values greater than 1.0 in conventional tests and nine lines (53%) had regression values greater than 1.0 in double-crop tests. Of the 33 lines in other quadrants, 13 lines (40%) had regression values greater than 1.0 in conventional tests and 17 lines (52%) had regression values greater than 1.0 in double-crop tests. Based on these percentages, there appeared to be no difference in regression values between those lines falling into the superior quadrant and all other lines. Figure 6 shows a scatter plot of regression values in conventional tests versus regression values in double-crop tests. Points coded "1" symbolize those entries falling into the superior quadrant; and points coded "0" symbolize those entries not falling into the superior quadrant. The general pattern of the graph indicates no relationship between an entry's regression value in conventional tests and its regression value in double-crop tests.

From correlation analysis of double-crop regression values and conventional regression values, it was concluded that there was no relationship between double-crop and conventional regression values considered ($r=-0.06$). A paired t test was conducted to determine if the mean difference between double-crop and conventional regression values was significantly different from zero. From these results, it was determined that the differences between regression values were not significantly different from zero ($P \leq 0.05$). Also, a t test was conducted to determine if the mean regression value for the superior group was significantly different from the mean regression value for the other group for either double-crop (1.02 versus 0.98, respectively) or conventional nursery environments (1.10 versus 0.97,

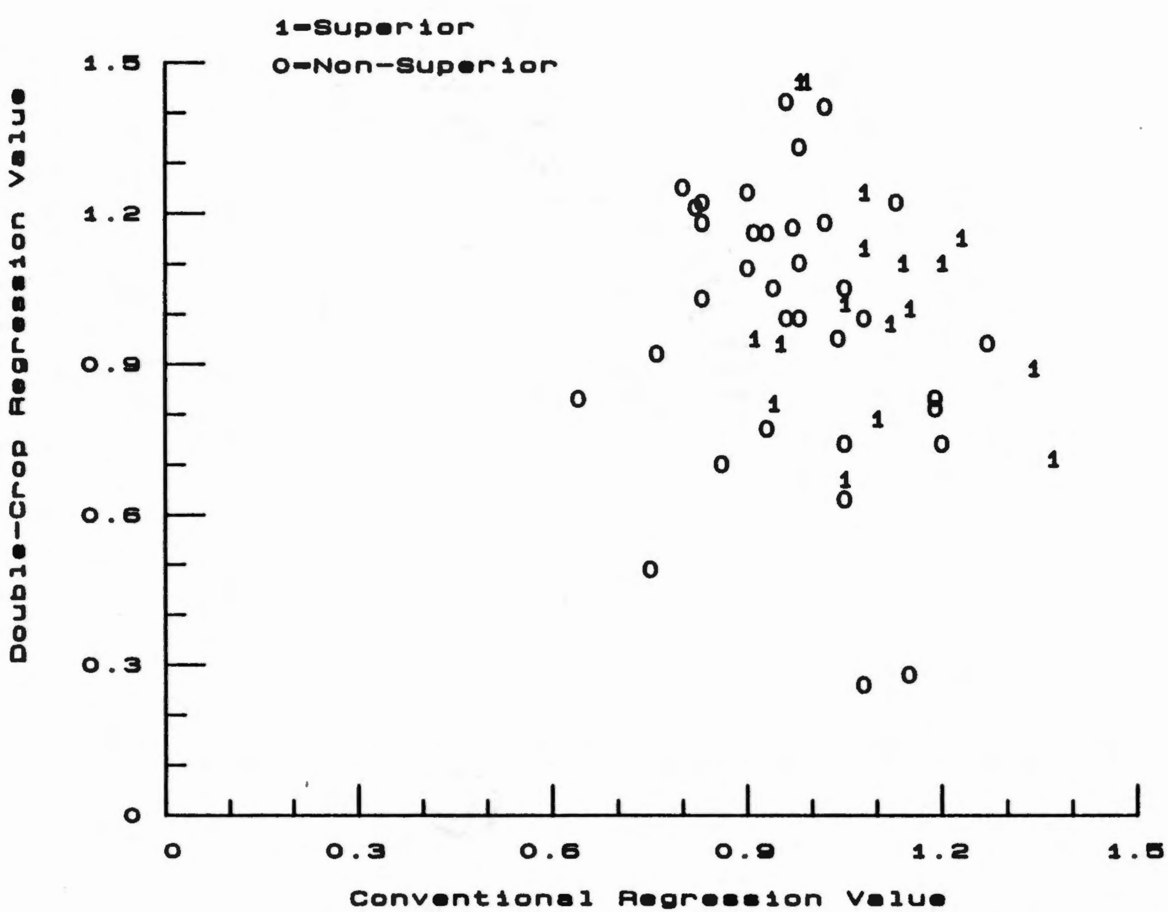


Figure 6. Scatter diagram of regression values for breeding line mean yield regressed on individual yield test mean for the superior group and non-superior group lines in double-crop versus conventional yield test nurseries.

respectively). For conventional nursery environments, there was a significant difference between the mean regression values of the superior and non-superior groups (Table 6). Observation of the mean regression value in conventional nursery environments for both the superior and non-superior groups shows that the superior group has a greater mean regression value than the non-superior group. However, in terms of a stability analysis, both groups would be considered stable. In double-crop nursery environments, there was no difference between the mean regression values of the two groups ($P \leq 0.05$).

The results from these analyses can provide some guidance in the use of stability analysis in selecting superior genotypes adapted for both conventional and double-crop production systems. There is a trend for superior genotypes to be more stable on the average than non-superior genotypes in conventional nursery environments, but this trend does not hold true in double-crop nursery environments. It would appear that the mean yield of the genotype in one nursery environment would be a better predictor of its performance in the other nursery environment than the use of regression values from a stability analysis. However, since the soybean breeder would desire a genotype with a high mean yield and a high (stable) regression value, selection based on a combination of both mean yield and stability in conventional nursery environments should provide a reliable means of selecting genotypes adapted to both conventional and double-crop production systems.

Table 6. Comparisons of the mean regression values of the superior group lines with the non-superior group lines in conventional and double-crop nursery environments.

Nursery Environment	Superior Group	Range	Non-Superior Group	Range	t Value†
Conventional	1.10 ±.03	0.91-1.37	0.97 ±.02	0.64-1.27	-3.11**
Double-Crop	1.02 ±.05	0.67-1.46	0.98 ±.05	0.26-1.42	-0.56

†** Significant at $P \leq 0.01$

CHAPTER V

SUMMARY AND CONCLUSIONS

The results from this study indicate: 1) that selection for superior soybean strains adapted to both conventional and double-crop production systems can be made in either conventional or double-crop nursery environments, and 2) that there is no appreciable difference in performance between determinate and indeterminate growth types.

The superior lines in conventional nursery environments tended to be the superior lines in double-crop nursery environments, and vice versa. Of the top ten lines in conventional tests, eight were among the top ten lines in double-crop tests; so the probability of identifying a line with superior yield in double-crop environments from selection in conventional environments is 80%. For the soybean breeder, the significance of these results is that it is not necessary to maintain separate nursery environments in order to select for lines which are superior yielding in conventional, double-crop, or both production systems. The ability to select for superior genotypes in only one nursery environment and produce superior genotypes adapted to other environments can result in considerable savings of time and resources in variety development.

Indeterminate growth types, were not found to be better adapted to double-crop production systems than determinate growth types. As a group, the determinate breeding lines in this study yielded significantly higher than indeterminate breeding lines in double-crop environments, but there was no difference in yield in conventional environments. However, among the superior breeding lines in this study, both determinate and indeterminate growth types were represented. These results indicate that the soybean breeder does not need to select for a particular growth type in order to facilitate development of cultivars adapted for either conventional or double-crop production systems. Selection based on mean yield, rather than plant growth type, should provide a more effective means of identifying superior breeding lines adapted to both conventional and double-crop production systems.

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APPENDIX

Table A-1: Names, pedigrees, and growth type classification of soybean entries used in this study.

ENTRY	PEDIGREE	GROWTH TYPE
Forrest	Dyer/Bragg	Determinate
Essex	Lee/S5-7075	Determinate
Tn77-31	Forrest/SRF 450	Indeterminate
Tn77-28	Forrest/SRF 450	Determinate
Tn82-58	D68-3297/Douglas	Determinate
Tn82-59	D68-3297/Douglas	Indeterminate
Tn82-278	J74-40/Douglas	Determinate
Tn82-32	J74-40/Douglas	Indeterminate
Tn82-279	Douglas/Centennial	Determinate
Tn82-37	Douglas/Centennial	Indeterminate
Tn82-280	Centennial/Franklin	Determinate
Tn82-65	Centennial/Franklin	Indeterminate
Tn82-281	Centennial/Franklin	Determinate
Tn82-66	Centennial/Franklin	Indeterminate
Tn82-282	Tracy/Franklin	Indeterminate
Tn82-68	Tracy/Franklin	Determinate
Tn82-179	Davis/TS72-824	Indeterminate
Tn82-283	Davis/TS72-824	Determinate
Tn82-284	Davis/TS72-824	Determinate
Tn82-70	Davis/TS72-824	Indeterminate
Tn82-71	Bragg/Mitchell	Indeterminate
Tn82-285	Bragg/Mitchell	Determinate
Tn82-286	Essex/Hodgson	Determinate
Tn82-287	Essex/Hodgson	Indeterminate
Tn82-288	J74-45/SRF 350	Determinate
Tn82-74	J74-45/SRF 350	Indeterminate
Tn81-2	Lee74/Mitchell	Determinate
Tn81-3	Lee74/Mitchell	Indeterminate
Tn82-75	D74-8819/TS72-824	Determinate
Tn82-76	D74-8819/TS72-824	Indeterminate
Tn82-183	D74-8819/TS72-824	Determinate
Tn82-77	D74-8819/TS72-824	Indeterminate
Tn82-78	D74-8819/TS72-824	Indeterminate
Tn82-184	D74-8819/TS72-824	Determinate
Tn82-81	D74-8819/Columbus	Indeterminate
Tn82-84	D74-8819/Columbus	Determinate
Tn82-82	D74-8819/Columbus	Indeterminate
Tn82-102	D74-8819/Columbus	Determinate
Tn82-289	Franklin/Forrest	Determinate
Tn82-290	Franklin/Forrest	Indeterminate
Tn82-291	J74-40/TS72-824	Determinate
Tn82-92	J74-40/TS72-824	Indeterminate
Tn82-129	Forrest/Miles	Determinate

Table A-1 (Continued)

ENTRY	PEDIGREE	GROWTH TYPE
Tn82-93	Forrest/Miles	Indeterminate
Tn82-191	Bedford/Mitchell	Indeterminate
Tn82-192	Bedford/Mitchell	Determinate
Tn82-193	Bedford/Mitchell	Indeterminate
Tn82-16	Bedford/Mitchell	Determinate
Tn82-292	Mitchell//Forrest/OK963	Indeterminate
Tn82-210	Mitchell//Forrest/OK963	Determinate
Tn82-293	Forrest//K1018/L73-977	Indeterminate
Tn82-294	Forrest//K1018/L73-977	Determinate

Table A-2: Names and locations of Tennessee Agricultural Experiment Stations at which conventional and double-crop tests were conducted in 1985 and 1986.

NAME	LOCATION
Knoxville Plant Sciences Field Laboratory †	Knoxville, Tennessee
Tobacco Experiment Station	Greeneville, Tennessee
Plateau Experiment Station	Crossville, Tennessee
Middle Tennessee Experiment Station	Spring Hill, Tennessee
Highland Rim Experiment Station	Springfield, Tennessee
Milan Experiment Station †	Milan, Tennessee
Ames Plantation	Grand Junction, Tennessee

† Tests were conducted at these locations from 1982-1986.

VITA

The author, Donald McLean Panter, Jr., was born in Atlanta, Georgia, on June 5, 1962. He attended elementary schools in Tennessee, North Carolina, and Oklahoma. He graduated from Lejeune High School, Camp Lejeune, North Carolina, in 1980. He entered The University of Tennessee, Knoxville in September, 1980 and received a Bachelor of Science degree in Agriculture in December, 1984 with a major in Plant and Soil Science.

In January, 1985 he entered Graduate School at The University of Tennessee, Knoxville working in the area of Plant and Soil Science. In August 1987, he was granted the Master of Science degree from The University of Tennessee, Knoxville with a major in Plant and Soil Science. While working toward the advanced degree, he was employed by The University of Tennessee as Senior Research Assistant for the Soybean Breeding Project.

He is the son of retired Marine Corps Master Gunnery Sergeant and Mrs. Donald M. Panter and is married to Jennifer Lee Sanders Panter.