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I am submitting herewith a dissertation written by Wayne Francis Whitehead entitled "High- versus Low-Stress Yield Test Environments for Selecting Superior Soybean (Glycine max L. Merr) Lines." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant and Soil Science.

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# HIGH- VERSUS LOW-STRESS YIELD TEST ENVIRONMENTS FOR SELECTING SUPERIOR SOYBEAN (*Glycine max* L. Merr) LINES

A Dissertation

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## DEDICATION

The author wishes to dedicate this dissertation to his deceased father, Paul Harrison Whitehead and to his beautiful wife, Farzaneh H. Whitehead and a little fireball of a son, Reza Paul Whitehead, for their love and support.

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## ABSTRACT

A problem that continues to perplex plant breeders is selecting for yield in stress versus non-stress environments. The purpose of this research was to select superior soybean lines which were best adapted to both low- and high-stress environments by using low- versus high-stress yield test environments.

Forty-eight random $F_4$ - derived lines were evaluated for yield over a five year period (1982-1986) at two locations [Crossville in East and Milan in West Tennessee] on high fertility, low acidity (low-stress), and low fertility, high acidity (high-stress) nursery environments at each location. Mean yields were 0.50 vs. 2.00 and 0.74 vs. 2.71 Mg $ha^{-1}$ for Crossville and Milan, high- vs. low-stress sites, respectively. Five additional locations throughout the state were included in 1985 and 1986 as yield trial testing sites for obtaining information about yield and broader adaptability.

Soil chemical and physical parameters of nursery environments were measured in 1984 and 1985 at each of the four nursery sites. The soil at the Crossville low-stress site was classified as a Typic Hapludult and the high-stress site was classified as an Aquic Fragiudult and Typic Hapludult. The soil at Milan low-stress site was classified as an Aquic Fragiudult over a buried Typic Ochraqualf and the high-stress site was classified as a Typic Fragiudalf and Glossic Fragiudult that intergraded to an Aeric Glossudalf. Soil bulk densities were taken at three soil depths at each site. The density measurements were in an

acceptable range (1.3-1.5 $m^{-3}$) which indicated that no physical barrier existed which would inhibit root penetration into the soil profile. Soil chemical analyses indicated that high acidity and aluminum concentration were major factors responsible for reduced availability of P, K, Mg, and Ca which caused yield reduction and poor growth in high-stress nursery sites.

Sixteen lines (33% selection intensity) were designated as the "superior" lines because their mean yields were above the grand mean in high-stress environments (0.62 Mg $ha^{-1}$) as well as above the grand mean in low-stress tests plus yield trials (2.25 Mg $ha^{-1}$). These sixteen lines served as the superior "standard" for the purpose of simulating selection. Eleven of the top 16 soybean lines came from 2 crosses (Essex x (Bay x N73-520 and Essex x Hodgson) and the top 3 superior lines came from the cross Essex x (Bay X N73-520).

Simulated selection, using either nursery type within location(s) for one year of testing, revealed 32 to 54% of the superior lines would have been selected. At least 1 of the top 3 superior lines would have been selected in every case, regardless of nursery type(s), location(s), or year(s) used. Combining high- or low-stress tests over location(s) in a given year or years (2 or 3) did not improve the effectiveness of selection enough to justify the extra time, expense, and labor for the purpose of selecting the highest yielding group ( one third) from a random set of lines in preliminary tests. Comparisons between 33 and 20% selection intensity generally revealed a lower probability in obtaining at least 1 of the top 3 superior lines using 20%, and in some cases the probability was zero. This indicates

that a selection intensity greater than 33% is inadvisable at the preliminary yield testing stage.

Stability analyses revealed that the sixteen superior lines had higher regression coefficients with 10 of those lines having regression coefficients greater that 1.00.

Analyses of plant height and maturity were conducted to determine if selecting the highest yieldig lines would have resulted in indirect selection of lines which were shorter and earlier or taller and later or any other combination. No trend of this type would have occurred.

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# PART 1: LITERATURE REVIEW AND EXPERIMENTAL PROCEDURES

# INTRODUCTION

A problem that continues to perplex plant breeders is selecting for yield or production traits in stress versus non-stress environments. In most cases the stated breeding goals are improving yield and quality but the basis for this is reducing genotype-environment interactions, that is, adaptation of plants (9, 10). Frankel (28) pointed out that in meeting the demands for varieties better adapted to changing conditions, the plant breeder is faced with the choice of breeding either for closely defined ecological conditions or for more varied conditions which include a considerable range of environments. Clearly the latter produces crops possessing general adaptability while the alternative approach is satisfactory for some situations such as horticultural crops grown in specialized environments. According to Devine (12) in order to utilize environments for crop production there are three alternatives available to man:

a) alter the natural environment by artificial means such as applying lime fertilizers and pesticides,

b) domesticate wild species which are adapted to adverse environments, or

c) genetically adapt crop species to adverse environments.

Theisen et al. (75) reviewed these alternatives and concluded that the first alternative is the most costly, the second is now being pursued with increasing vigor, while the third is currently receiving

considerable attention. Thus, from the very inception of a breeding program for developing crop cultivars to fit an edaphic stress environment, the expertise of both soil science and plant breeding are needed for problem definition and goal development.

The optimum environment in which to practice selection is one which provides the greatest differential genetic manifestation for the attribute(s) being selected. Fundamental to the development of crop cultivars for tolerance to edaphic stresses is the development of techniques and procedures for ascertaining plant responses to the pertinent stress factors. Falconer and Latyszewski (16) reported on selection of mice under stress (75% of the normal food intake between the ages of weaning and weighing) and non-stress (mice strain fed ad lib) conditions. The major points they found are best stated in their own words:

a) "Improvement of the genotype for rapid growth on a high plane of nutrition carried with it no improvement for growth on a low plane. But improvement of the genotype for growth on a low plane did carry with it a considerable improvement of the genotype for growth on a high plane.

b) Heritability was higher in restricted diet strain (though not significantly so), being 29% on restricted diet and 20% on full." The conflicting evidence on which type of environment, stress versus non-stress, is best for selecting high and stable performance among plant genotypes is a question of major importance.

The objectives of this study were to determine (1) a standard which shows the top sixteen and three highest yielding soybean lines

(out of 48 lines) which are superior performers in both low and high productivity environments by using only low-stress (high pH and fertility) or high-stress (low pH and fertility) yield test nursery environments, (2) if the top sixteen and three superior yielding soybean lines are the most stable genotypes which perform best in both low-stress and high-stress nursery environments, and
(3) the soil chemical and physical properties responsible for reduced yields of the soybean lines.

# CHAPTER 1

# LITERATURE REVIEW

## Selection and Stability of Plant Genotype Lines in Stress versus Low-Stress Environments

Foy (25) in 1983 proposed a plant breeding approach which involves the identification of both present and potential growth-limiting factors in problem soils through screening of germplasm for tolerance, elucidating the genetic, physiological and biochemical mechanisms of stress tolerance, and the selection or breeding of stress tolerant cultivars. A more promising approach for discovering stress tolerance mechanism is to use stress tolerant and sensitive genotypes of closely related plants (preferably near-isogenic lines) of the same species (20).

Allen et al. (2) conducted research to determine the type of yield trial environment which would foster maximum progress through selection. The five crop species used were barley, Hordeum vulgare L.; wheat, Triticum aestivum L.; oats, Avena sativa L.; soybean, Glycine max. L. Merr; and flax, Linum usitatissimum L. They found that favorable environments (high yield) were superior to intermediate environments by 7% and 4% for soybean and wheat, respectively, but for barley, oats and flax, there were no indications that high yield environments were superior. They based their findings on the magnitude of correlation between a genotype relative to a test environment ($\underline{y}$) and a genotype relative to the entire population of environments in

which a selected genotype would be used ($\bar{y}$). Their results indicated that if any class of environments is eventually established as substantially superior for testing purposes, it will be because the correlation between $\underline{y}$ and $\bar{y}$ is comparatively high for that class of environments (2).

Johnson and Frey (39) performed heritability studies on oats at varying levels of environmental stress. The characters they studied (plant weight, number of panicles per plant, grain yield) varied in their reactions to stress. They indicated that stress reaction should be qualified by the attribute under consideration, i.e., stress for yield. They defined stress environment as one in which mean yield performance is low, relative to performance in other environments. In general, they found that genotypic variance among oat cultivars increased as the environmental stresses were reduced (39). However, the environmental variance also tended to increase so that heritabilities did not always increase with reduced environmental stress. They concluded that since the findings were inconsistent, it was not appropriate to conclude that non-stress conditions were the best for conducting selection for yield.

Gotoh and Osanai (34) practiced selection for high spike number for four generations ($F_3$ through $F_6$) and high yield for 1 generation ($F_7$) in three bulk samples (each grown at a different seeding rate) of a wheat cross. They obtained the highest yielding and most widely adapted wheat lines from the low-fertility environment (34). Byth et al. (8) did research with soybean for determination of specific and non-specific index selection. They found that the use of high

performance environments resulted in maximum predictions of genetic advance, but actual yield advance evaluated over environments was essentially equal for all environments tested (8). From their findings they surmised that actual advance evaluated over environments may be the only accurate criterion for comparison of selection procedures in the presence of substantial genotype X environment interactions. Vela-Cardenas and Frey (77) conducted a study for a 2 year period to determine the optimum environment for maximizing heritability and genetic gain from selection for several traits of oats. All ten test environments were equally efficient in maximizing relative genetic gains from selection for seed weight; however, the low fertility environments were optimum for heritability.

Rosielle and Hamblen (59) in 1981 examined from a theoretical standpoint the question "What selection criteria are needed when lines are grown in stress and non-stress environments?" Tolerance to stress was defined as the difference in yield between stress and non-stress environments, while mean productivity is the average yield in stress and non-stress environments. They concluded that the situation most favorable to plant breeders would be one in which genetic variance in stress environments is greater than that in non-stress environments and genetic correlation between yields in stress and non-stress environments are highly positive. Under these circumstances tolerance and mean productivity will be positively correlated with one another and with yields in both stress and non-stress environments. Unfortunately these situations appear to be rare. In their view, the most desirable approach would be to choose testing sites that are

representative of the conditions for which a breeder wishes to improve yield.

Since the release of broadly adapted varieties of wheat, such as Penjamo 62, Pitic 62, from the CIMMYT (Centro Internacional de Mejoramiento de Maiz Trigo) breeding program, a large collection of methods have been proposed for assigning numerical indexes to describe the production response and stability characteristics of plant genotypes (41). It is commonly observed that the relative performance of different genotypes are altered in different environments i.e., there exists a genotype by environment interaction (GxE). Comstock and Moll (13) said that phenotypic expression depends on the environment and the evaluation of the environment depends on the genotype.

Many researchers (8, 14, 15, 17, 18, 19, 39, 41, 48, 55, 56, 57, 59, 70) have proposed and/or evaluated various statistical methods as criteria in selecting for high and stable performance of plants. The most widely used criteria for selecting for high and stable performance are mean yield, regression of yield of individual genotypes on site mean yield, and deviation from regression (15, 18, 29, 41), but other methods have been employed (67, 80).

Sprague and Federer (74) showed how variance components could be used to separate out the effects of genotypes from environments and their interaction by equating the observed mean squares in the analysis of variance to their expectations in the random model. The model used:

$$Y_{ijk} = \mu + d_i + e_j + g_{ij} + \varepsilon_{ijk} \qquad (1)$$

$$\sum_i d_i = \sum_j e_j = \sum_{ij} g_{ij} = 0$$

where

$Y_{ijk}$ = yield of $k^{th}$ replicate of the $i^{th}$ genotype in the $j^{th}$ environment and = general mean, $d_i$ = genotype effect, $e_j$ = environmental effect, $g_{ij}$ = interaction effect, $_{ijk}$ = random error. This procedure was followed by Milliken and Graybell (58) in considering G X E interactions.

Partitioning of G X E interactions was given by Yates and Cochran (81), but was predominately overlooked for 20 years. Their findings showed that the relationship between general fertility (as indicated by the mean of all varieties) and variety yield could be investigated by regressing the yields of each variety on the mean yields of all varieties across locations or sites. That is, $g_{ij}$ in equation (1) is regressed on $e_j$:

$$g_{ij} = \beta_i \varepsilon_j + \delta_{ij}, \qquad (2)$$

where $\beta_i$ is a linear regression coefficient for the ith genotype and $\tilde{o}_{ij}$ the deviation from regression. Using equation 2, then equation 1 can be written thus:

$$Y_{ijk} = \mu + d_i + (1 + \beta_i) e_j + \delta_{ij} + \varepsilon_{ijk} \qquad (3)$$

Yates and Cochran showed that this regression accounted for a large part of the interaction in a set of barley trails, but their ideas were not effectively utilized until Finlay and Wilkinson (18) proposed and used the method for analyzing adaptation of 277 varieties of barley in seven environments. This method was also used by Perkins and Jinks (55) for estimating genetic parameters in a biometrical model.

The formal analysis of variance for GxE interactions is given in an identical manner by Yates and Cochran (81), Finlay and Wilkinson (18) and Perkins and Jinks (55). In the notation of Perkins and Jinks, there are t genotypes and s environments with the interaction partitioned into two components: (i) heterogeneity of regression with t-1 degrees of freedom and (ii) deviation from regression with (t-1) (s-2) degrees of freedom. Each of these terms can be compared with the residual experimental error, and heterogeneity of regression further compared with the deviations in order to see if it accounts for a significantly large part of the observed interaction. This particular approach, now commonly known as joint regression analysis, has been widely adopted in practice (29, 37, 51).

Regression methods were also considered by Rowe and Andrew (60) and Eberhart and Russell (15), who pooled the sum of squares for environments and GxE interactions and repartitioned them. Eberhart and Russell suggested that regression was a response index and that the mean square for deviations from regression provided the real index of a variety's stability of production. A problem with this approach as pointed out by Freeman and Perkins (30), is that the sum of squares for the linear component among environments, which is allocated one degree of freedom, is the same as the total sum of squares for environments with (s-2) d.f. Perkins and Jinks (55) recognized that the environmental sum of squares is the same as that for the combined regression over all genotypes but did not use it and avoided this difficulty.

One of the main reasons for evaluating genotypes in a wide range of environments is to estimate their stability. Langer et al. (41) compared the relationship between several indexes previously proposed for measuring crop (oats) cultivar responses and stabilities over variable environments. They also suggested two easily computable indexes that might be used in the early screening stages of strain testing. The indexes of each variety via the proposed model of Eberhart and Russell (15) were also included in the comparison. This method utilizes the grand means of experiments as production indexes for environments and it provides regression response indexes (b values) and mean squares for deviation from regression ($S^2_d$) as indexes of stability.

These previously mentioned indexes were compared by correlating the arrays of indexes for varieties within variety sets. Langer et al. (41) suggested that it is possible to select oat varieties with any combination of production response and production stability. Also their results demonstrated that although there may be correlations among these traits in random populations, production response and production stability are relatively independent of one another. From another experiment, Langer et al. (42) concluded that regression response indexes are real characteristics of varieties and that different reports of high correlations for yield versus low correlation of regression response indexes are due to the degree of selection intensity that had been applied to the experimental materials.

To test if there are differences among genotypes, it is usually important to decide whether the environments should be considered as fixed or random. In most experiments in which genotypes are tested in a range of environments it is often assumed that the environments are a random sample of possible environments.

Frankel (28) concluded that those who wish to infer the behavior of genotypes in other environments should at least insure that the new environments come, so far as is possible, from the same population from which the experimental environments are a sample. Furthermore, he concluded that if an interaction is largely expressible in terms of linear effect, then it may be reasonable to assume that for a new environment with a mean in the range of those tested, the genotypes will behave in the same relative fashion as in the environments sampled (28). A measure of the suitability of the environment for discriminating among genotypes is needed. The difficulty in discriminating among genotypes arises from variation occurring in more than one dimension (36). Dowker (13) suggests that in a practical breeding program it is desirable to capitalize on GxE interactions present in order to find those environments in which the genotype effects of interest may be maximized.

## Important Soil Considerations in High- and Low-Stress Environments

The productivity of a soil is influenced by the nature of its subsoil, which is subjected to little field alteration except drainage. Although roots normally do not penetrate deeply into subsoil, the permeability and chemical nature of the subsoil

influences the surface soil in its role as a medium for plant growth (7).

It has been well documented that soil compaction adversely influences soybean growth and production. Several researchers have analyzed the effects of soil compaction on root growth of soybean ( 5, 6, 32, 35, 58). In general their results indicated that:

(a) increased soil strength reduces root elongation but increases root diameter;

(b) decreased water content at a specific bulk density increases root growth compared to growth when the soil is saturated;

(c) decreased water content usually increases soil strength, especially for sandy loam or coarser soils; and

(d) soil compaction can either decrease or increase mineral uptake, depending on whether root interception, root diameter, or the diffusion coefficient for nutrients is the most important parameter controlling uptake.

Soil compaction and many unfavorable conditions of the soil environment limit the development and function of soybean root systems (68). Compensatory root growth, one of many avoidance mechanisms, has been reported to consume more carbon per gram of root than non-stressed (non-compacted soils) controls (64). Since root systems of soybean plants appear to allocate more carbon in compacted soils, less is utilized for the biological fixation of nitrogen (64).

Acid soils are an insidious problem which may reduce fertilizer and water use efficiency of plants and can be mistaken for nutrient

deficiency, drought injury, herbicide injury, low temperature damage, or plant disease (25). Acid soil toxicity is a complex of factors that may affect the growth of various plants through different physiological pathways, most likely controlled by different genes.

Growth limiting factors associated with soil acidity include toxicity of Al, Mn and other metal ions, low pH (H+ toxicity), and deficiency or unavailability of essential elements such as Ca, P, Mg, Mo and others (25, 45). Acid soil factors may act independently or together to affect the growth of plants.

Mineral stress of plants in problem soils cannot always be economically ameliorated with current technology (25). An alternative is to breed crop varieties with greater tolerance to mineral toxicity or deficiency. The opportunity to capitalize on crop adaptation to defined soil stresses may become available at any stage in a breeding program (12). Perhaps the most important benefits from a plant breeding approach to solving soil fertility and pH problems are that it is ecologically clean, energy conserving, and cheaper than amending the soil. Thus, it is compatible with national and international goals of economical food production, conservation of fertilizers and energy, and control of pollution. An example of this approach is increased crop yields on stressed production areas with Fe-efficient strains of weeping lovegrass, Eragrostis curvula (Schrad.) Nees, and soybean for calcareous soil (4, 79). Another example would be the expanding of crop acreage to marginal soils with Al-tolerant wheat cultivars of the Campo Cerrado of Brazil (69).

Aluminum and manganese toxicities are the major growth-limiting factors in many acid soils of the world (22, 23, 40, 47). Both Al and Mn interact with other mineral elements (Ca, P, Mg, Fe, Si, etc.) in the soil and in the plant (21, 24). Plant symptoms of Mn toxicity are detectable at stress levels which produce little or no vegetative growth reduction. By contrast, Al toxicity can sometimes reduce yields substantially without the appearance of clearly identifiable symptoms in plant tops (21). Hence, growth reductions in acid soils may be largely or wholly attributed to excess Mn, when excess Al is the most important. The effects of excess Al and Mn on a wide range of plants have been reported elsewhere (4, 22, 23, 71, 74).

The fact that tolerance to excess Al and Mn may be quite specific among plant genotypes means that a breeder must be very careful in determining the levels of these elements in soils he is using to breed cultivar tolerance. Aluminum tolerance in certain cultivars of wheat, barley, soybean and snapbean are associated with the ability to resist Al-induced Ca deficiency (27). Huett and Menary (38) found that 500 ppm Ca in nutrient solution completely overcame the detrimental effect of Al on yield of cabbage, lettuce and kikuyu grass. Sartain and Kamprath (61) concluded that Ca uptake by soybean from a limed soil zone was reduced by the presence of Al translocated from the unlimed zone. Aluminum affected the uptake of Ca more than P.

Manganese toxicity is often associated with a decrease in Ca concentration in plants (37, 72). The addition of Ca to the growth medium sometimes reduced Mn accumulation, decreased the severity of Mn-induced chlorosis, and alleviated growth reductions.

In many plant species, Al tolerance is closely related to P use. For example, in certain genotypes of wheat, tomato and maize, Al tolerance coincides with tolerance to low P levels in nutrient solutions, either in the presence or absence of Al (25). Also, tolerance to Al and tolerance to low P coincided in certain cultivars of wheat and beans. Sartain and Kamprath (61) found that Al-tolerant soybean cultivars absorbed more P per unit of root length than Al-sensitive ones. Foy (20) found that phosphorus additions can reduce the toxicity of Mn by rendering it inactive within the plant. Aluminum tolerance has been associated with greater uptake of K and Mg in potato cultivars and with greater Mg uptake in maize lines (20). Parker et al. (53) found that nutrients other than Mn in plant tissue were not affected by Mn treatments; however, small differences occurred among soybean cultivars in concentration of K, Ca, Mg in leaves and seeds. Lee (44) noted that hydroxy Al was toxic to maize seedlings, but Al citrate was not. THe addition of humic acid also ameliorated Al toxicity at pH 4.7.

The correction of Al and Mn toxicities by liming is not always economically feasible, especially Al toxicity in strongly acid subsoils. However plant species and varieties within species differ widely in their tolerance to both factors, and some of these differences are genetically controlled (21). Hence, a reasonable alternative or supplementary approach to the problem is to select or breed plant genotypes with greater tolerance to excess Al and Mn which may alleviate other elemental deficiencies.

# CHAPTER 2

# EXPERIMENTAL PROCEDURES

## High- and Low-Stress Sites and Locations

The research was started in 1982 at the Plateau Experiment Station (PES, Crossville) in East Tennessee and the Milan Experiment Station (MES, Milan) in West Tennessee. Both locations were chosen on the basis of specific edaphic conditions and the range of climatic conditions they represent. Each location consisted of a low- and high-stress site.

The field conditions at initiation of the research were a) low-stress: optimum pH (6.1-7.0), phosphorus (medium), potassium (low-medium), and b) high-stress: low pH (4.5-5.0), phosphorus (medium), potassium (low). The low-stress sites at both locations had been under previous cultivation representing normal agronomic practices in Tennessee, whereas the high-stress sites had been recently cleared from mixed hardwood forests and represented sub-optimum conditions for crop growth. These sites (hereafter referred to as nursery sites) were kept under these conditions by application of 336 kg $ha^{-1}$ of 0-20-20 fertilizer to the low-stress sites and no fertilizer or lime added to the high-stress sites during each year of the study.

The soil classifications as well as some chemical and physical parameters for each site at each location were determined in 1984 and 1985. For chemical analyses, a soil sample was taken from each plot

at each nursery site. Plot size was 6.10 meters long and 0.92 meters wide. One hundred and fifty surface and 150 subsoil samples were taken at PES and MES low-stress sites. At the Milan high-stress site, 150 surface and 333 subsoil (an additional 183 subsoil samples came from morphogenic differences of subsoil profile) samples were taken making a total of 1383 collected from both locations.

Chemical Extractions and Determinations

The samples were analyzed for Al, Mn, K, Ca, P, Mg, C, and pH. Two methods of extraction for manganese ($Mn_1$ and $Mn_2$) were used. Method 1 was for water-soluble manganese ($Mn_1$)(1,66), while Method 2 was for exchangeable manganese (1). The potassium chloride extraction procedure outline by Barnhisel and Bertsch (7) was used to extract aluminum. The magnesium, calcium and potassium extraction was included in the method 2 extraction of manganese except that:

a) 10 ml of saturated CaCl were added to 5 ml of K sample solution (to prevent ionization of K), and
b) 50 ml of lanthanum were added to 5 ml of Ca sample solution (to prevent formation of $CaPO_4$, $CaSO_4$ and other salts as well as some ionization).

The determination of previously stated elemental concentration was conducted on the Perkin-Elmer 5000 Atomic Absorption Spectrophotometer (31,54). For extracting phosphorus (P) a dilute-double-acid extraction procedure was employed (52). The P content was determined by the procedures of Thomas and Peaslery (76). Two methods were employed to determine pH: a $H_2O$ method and KCl method (46).

The percent of carbon was determined on a CR-12 Carbon System 781-600 furnace. The procedure is discussed in the preliminary instruction manual from Leco Corporation (43).

Preliminary tests showed the soils at PES (both sites) and MES low-stress site to be uniform. However, the MES high-stress site did not appear to be uniform, so the same analytical procedures were performed on all samples (483) to determine the variation among plots. A total of 556 soil samples from both locations were analyzed.

Soil physical parameters were observed at three depths on two soybean lines per nursery site for two replications (soil pits). The exception was the MES high-stress site which had three replications. Soil pits (2 x 2 x 2 m) were dug with a tractor mounted back-hoe at each nursery site at each location adjacent to two soybean genotypes. Where possible, the pits were dug adjacent to same two soybean lines at each nursery site. The profile descriptions (morphological and taxonomical) of each nursery site at each location are shown in Tables A1-A9 of the Appendix.

To evaluate the root distribution and penetration into the soil profile at each site, a 12.7 cm long x 12.7 cm wide x 38.1 cm deep column of soil was taken from each of the two soybean lines along the pit wall. Each column was divided into three equal sections to determine an approximate root mass present within each 12.7 cm depth. Bulk density was determined at each site in close proximity to each pit using the procedure of Veihmeyer and Hendrickson (78). The bulk densities were measured for each of the 12.7cm depths stated above so

that a relationship could be determined between the root mass and bulk density.

Five additional locations [Knoxville (KLS), Grand Junction (ALS), Springfield (HRLS), Spring Hill (MTLS), and Greenville (GLS), Tennessee] were added in 1985 and 1986 for the purpose of providing information about yield and broader adaptability of the soybean lines. These locations will be referred to hereafter as "yield trials". Soil test results of yield trial locations are shown in Table A.12 of the Appendix.

## Plant Material

Forty-eight soybean lines were chosed at random in the $F_5$ generation from six crosses for use in this study. These crosses are shown in the following table:

Table 1. The pedigree and number of soybean lines of each cross used in this research.

| Crosses | No. of Lines |
|---|---|
| Essex x (Forrest x OK963) | 8 |
| Essex x Hodgson | 8 |
| J74-45 x Ts72-824 | 8 |
| J74-40 x Ts72-824 | 8 |
| Essex x (Bay x N73-520) | 8 |
| Centennial x J74-45 | 8 |

The six crosses represent a range of "typical" parental stocks that might be used by soybean breeders in similar maturity zones (IV-VI) of the Southeast. Two check cultivars, 'Forrest' and 'Essex', were included as a basis for comparison.

## Experimental Design and Statistical Procedure

The experimental design used in this study was a randomized complete block with three replications per nursery site. The plot size per nursery site consisted of 1 row (Plateau sites, all years), 2 rows (Milan high-stress, all years), and three rows (Milan low-stress, all years, plots in yield trials, 1985-1986) were 6.10 m long with 0.92 m spacing between rows. The data taken consisted of seed yield and seed moisture content, maturity and plant height (KLS, PES, MES only), and lodging (PES and MES only).

Analyses of variance were conducted on yield to determine statistical differences among genotypes for individual year-location-sites. In addition, combined analyses of variance were conducted for low-stress sites and for high-stress sites combined across locations and years in order to determine statistical differences for yield among years, locations, genotypes and their interactions (33,50,63,73). The model used was:

$$Y_{ijkm} = \mu + y_i + l_j + yl_{ij} + r_k(yl_{ij}) + g_m + gy_{mi} + gl_{mj} + gyl_{mij} + e_{ijkm}$$

where:

$Y_{ijkm}$ = Yield of the $m^{th}$ Genotype within the $k^{th}$ Replication at the $j^{th}$ Location for the $i^{th}$ Year

$\mu$ = overall Mean yield

$y_i$ = the effect of the $i^{th}$ year (fixed)

$l_j$ = the effect of the $j^{th}$ location (fixed)

$y_i l_j$ = the effect of the $i^{th}$ year by $j^{th}$ location interaction

$r_k(y_i l_j)$ = the effect of the $k^{th}$ replication within $i^{th}$ year by $j^{th}$ location interaction

$g_m$ = the effect of the $m^{th}$ genotype

$g_m y_i$ = the effect of the interaction of the $m^{th}$ genotype with the $i^{th}$ year

$g_m l_j$ = the effect of the interaction of the $m^{th}$ genotype with the $j^{th}$ location

$g_m y_i l_j$ = the effect of the interaction among the $m^{th}$ genotype within the $k^{th}$ replication at the $j^{th}$ location for the $i^{th}$ year

$e_{ijkm}$ = random error associated with the $m^{th}$ genotype within the $k^{th}$ replication at the $j^{th}$ location for the $i^{th}$ year

Finally, using a completely random model, analyses of variance were conducted for yield across all yield trial locations each year and combined across years in order to determine statistical differences among years, locations, genotypes and their interactions.

The yield stability of each soybean line was determined by regressing the individual line's mean yield at a site on the site mean (yield of all lines) across sites, locations, and years (15). The Statistical Analysis System (SAS) (62) was utilized for the above analyses.

The 48 lines were ranked from the highest to lowest based on their mean yield over four years, all nursery sites and yield trial locations (1986 MTLS excluded) for the purpose of simulating truncated selection. Selection intensities of 33% and 20% were used in order to simulate the selection intensity that soybean breeders might use at preliminary yield testing stages. This ranking provided the basis by which the lines were separated into superior and non-superior groups. Relative rankings of the mean yield of all lines were made for each year and combinations of years (2 and 3 year combinations) for individual sites, locations, and their combinations. Finally, the percentage of the superior genotypes found in the previous mentioned year-location-site combinations was calculated. Since the percent data ranged from 0 to 100%, an arc sine transformation (33) was conducted for the purpose of performing Duncan's Multiple Range mean separation tests (33, 62). The previously mentioned rankings, percentage calculations, and mean separations provided the bases for comparing simulated selection for yield in the low-versus high-stress environments. SAS (62) was utilized for the above analyses.

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# PART 2: HIGH- VERSUS LOW-STRESS YIELD TEST NURSERY ENVIRONMENTS FOR SELECTING SUPERIOR SOYBEAN (*Glycine max* L. Merr) LINES

## ABSTRACT

Eight random $F_4$-derived lines from each of six crosses (48 lines total) and two check cultivars were evaluated for yield over five years (1982-1986) on high fertility, low acidity sites (low-stress nursery environments) and on low fertility, high acidity sites (high-stress nursery environments) at two locations each year. Five additional locations in Tennessee were included in each of 1985 and 1986 as yield trial testing sites for obtaining pertinent information about yield and broader adaptability. Mean yields were 0.74 vs. 2.71 and 0.50 vs. 2.00 Mg $ha^{-1}$ for Milan and Crossville, high- vs. low-stress tests, respectively.

Bulk densities were taken at three soil depths at each of the four sites. The density measurements were in an acceptable range (1.3-1.5 Mg $m^{-3}$) which indicated that no physical barrier existed that would inhibit root penetration into the soil profile. Soil chemical analyses indicated that high aluminum concentration and low pH were major factors responsible for reduced availability of P, K, Mg, and Ca which caused yield reduction and poor growth in high-stress tests. Sixteen lines (33% selection intensity) were designated the "superior" lines because their mean yields were above the grand mean in high-stress (0.62 Mg $ha^{-1}$) as well as above the grand mean in low-stress tests plus yield trials (2.25 Mg $ha^{-1}$). Simulated selection using individual nursery type within locations and years revealed that 32 to 54% of the superior lines would have been selected using either type of nursery in one location per year. At least one of the top three lines would have

been chosen in every case, regardless of type of nursery environment(s), location(s), or year(s) used. The top 3 superior lines came from one cross, Essex x (Bay x N73-520). Combining high- or low-stress nurseries over location(s) in a given year resulted in only slight improvement in the effectiveness of selection. Testing entries for two years did not improve the effectiveness of selection enough to justify the extra time and expense of preliminary yield testing for the purpose of selecting the highest yielding group ( ≈ one-third) from a random set of lines. Comparisons between 33 and 20% selection intensity revealed that the probability of obtaining at least one of the top 3 superior lines was generally lower for 20% vs. 33% selection intensity and in some cases the probability would have been zero using 20%. This indicates that a selection intensity greater than 33% is inadvisable at the preliminary yield testing stage.

Stability analyses revealed that the sixteen superior lines had higher regression coefficients, with 10 of those lines having regression coefficients greater than 1.00. Analyses of plant height and maturity were conducted to determine if selecting the highest yielding lines would have resulted in indirect selection of the lines which were shorter and earlier or taller and later or any other combination. No trend of this type would have occurred.

# CHAPTER 1

## INTRODUCTION AND LITERATURE REVIEW

In most plant breeding programs, the stated breeding goals are improving yield and quality but the basis to this is reducing genotype-environment interactions, that is adaptation of plants (6). Frankel (15) pointed out that in meeting the demands for varieties better adapted to changing conditions, the plant breeder is faced with the choice of breeding either for closely defined ecological conditions or for more extensive breeding conditions which include a considerable range of environments.

According to Devine (8) in order to utilize environments for crop production there are three alternatives available to man: i) alter the natural environments by artificial means such as applying lime, fertilizers and pesticides, ii) domesticate wild species which are adapted to adverse environments, or iii) genetically adapt crop species to adverse environments. Theisen et al. (33) reported that, from the very inception of a breeding program for developing crop cultivars to fit edaphic stress environments, the expertise of both soil science and plant breeding is needed for problem definition and goal development. Rosielle and Hamblen (30) concluded that since positive correlation between plant tolerance and mean productivity and with yield in both stress and non-stress environments is rare. They suggested that the most desirable approach for plant breeders would be to choose testing sites to be representative of the production

conditions for which a breeder wishes to improve yield. Dowker (9) suggested that in a breeding program it is desirable to capitalize on GE interactions present in order to find those environments in which the genotypic effects of interest may be maximized. Comstock and Moll (7) reported that the phenotypic expression depends on the environment and the evaluation of the environment depends on the genotype. A common method used to clarify the relative amount of stress at a particular location/year is to use the grand mean yield of a fixed or random set of genotypes in a particular test at that site, which is referred to as site mean (2, 11, 13, 29, 36).

Johnson and Frey (21) found that genotypic variance for yield among oat cultivars increased as environmental stresses were reduced. However, the environmental variance also tended to increase so that heritabilities did not always increase with reduced environmental stress. They concluded that since these findings were inconsistent, it was not appropriate to conclude that non-stress conditions were the best for conducting selection for yield.

Allen et al. (2) found that favorable environments (high yield) were superior to intermediate environments by 7% and 4% for soybean and wheat, respectively, but for barley, oats and flax, there were no indications that high yield environments were superior. They based their findings on the magnitude of correlation between a genotype relative to a test environment ($\underline{y}$) and a genotype relative to the entire population of environments in which a selected genotype would be used ($\bar{y}$). Vela-Cardenas and Frey (34) found that the range of favorable and unfavorable environments which they evaluated were

equally efficient in maximizing genetic gain from selection for oat seed weight. Byth et al. (5) found that the use of high performance environments resulted in maximum prediction of genetic advance but actual soybean yield advance was essentially equal for all environments. Gotoh and Osanai (19) practiced selection for high spike number for 4 generations ($F_3$ through $F_6$) and high yield for 1 generation ($F_7$) in 3 bulk samples (each grown at a different seeding rate) of a wheat cross. They obtained the highest yielding and widely adapted wheat lines from the low-fertility environment.

Many researchers (7, 10, 11, 12, 13, 21, 23, etc.) have used varying statistical methods as criteria in selecting for high yielding and stable performance of plant species in breeding programs. One of the most widely used criteria for selecting plant species with high and stable performance is proposed by Eberhart and Russel (11). The criteria they used are mean yield, regression of genotype response on site mean yield and deviation from regression. They suggested that the deviation from regression provided the real index of a variety's stability of production.

The objectives of this study were i) to set up an overall standard showing the top sixteen, ten, and three superior lines (33, 20, and 67% selection intensities, respectively) which were highest yielding in both low- and high-stress nursery environments to determine if there are differences among appropriate year-site-location combinations for percentage of superior soybean lines, ii) if these superior lines are the highest and most stable, and iii) define the

soil physical and chemical properties of low- and high-stress nursery environments.

# CHAPTER 2

## MATERIALS AND METHODS

The research was started in 1982 at the Plateau Experiment Station (PES, Crossville) and the Milan Experiment Station (MES, Milan) in East and West Tennessee, respectively. The field conditions at initiation of the research were 1) low-stress: optimum pH (6.1-7.0), phosphorus (medium), potassium (low-medium), and b) high-stress: low pH (4.5-5.0), phosphorus (medium), potassium (low). The low-stress sites had been under previous cultivation representing normal agronomic practices in Tennessee, whereas the high-stress sites had been recently cleared from mixed hardwood forests and represented sub-optimum conditions for crop growth. These sites (hereafter referred to as nursery sites) were kept under these conditions by application of 336 kg $ha^{-1}$ of 0-20-20 fertilizer to the low-stress sites and no fertilizer or lime added to the high-stress sites during each year of the study. Five additional yield trial locations [Knoxville (KLS), Grand Junction (ALS), Springfield (HRLS), Spring Hill (MTLS), and Greeneville (GLS), Tennessee] were added in 1985 and 1986 for the purpose of providing information about yield and broader adaptability of the soybean lines. Soil test results of yield trial locations are shown in Table A-12 of the Appendix.

Soil profile classification and soil chemical (Al, Mn, K, Ca, P, Mg, C, and pH) and physical (bulk density) parameters were determined in 1984 and 1985, respectively. A soil sample was taken from each

plot (6.10 m long and 0.92 m wide) at each nursery site. One hundred and fifty surface and 150 subsoil samples were taken at PES and MES low-stress sites. At the Milan high-stress site, 150 surface and 333 subsoil (an additional 183 subsoil samples came from morphogenic differences of subsoil profile) samples were taken making a total of 1383 collected from both locations for chemical analyses.

The soil chemistry for Mn, Mg, Ca, and K was extracted using Adams (1) exchangeable manganese procedure, Al using Barnhisel and Bertsch (3) KCl procedure, and P using Olsen and Sommers (26) dilute-double-acid procedure. All previous elemental concentrations were determined on Perkin-Elmer 5000 Atomic Absorption Spectrophotometer (17, 28) except P being determined by a Technicon Auto Analyser (26). The C% was determined using CR-12 Carbon System 781-600 furnace (24) and pH by McLean (25) water and KCl method. A total of 556 soil samples from both locations were analyzed. The soil bulk density was measured at three depths (12.7 cm increments) on two soybean lines (duplicated at each site) per nursery site for two replications (soil pits, 2 x 2 x 2 m). The exception was the MES high-stress site with three replications. Root mass was collected in each replication from a 12.7 x 12.7 x 38.1 cm soil core which was divided into three 12.7 cm cube sections. Bulk density (35) was measured at same depths mentioned so a relationship between bulk density and root mass could be determined.

Forty-eight $F_4$-derived soybean lines were chosen at random from six crosses to be used in this study. These crosses are shown in Table 2.

Table 2. The pedigree and number of soybean lines of each cross used in this study.

| Crosses | No. of Lines |
|---|---|
| Essex x (Forrest x OK962) | 8 |
| Essex x Hodgson | 8 |
| J74-45 x Ts72-824 | 8 |
| J74-40 x Ts72-824 | 8 |
| Essex x (Bay x N73-520) | 8 |
| Centennial x J74-45 | 8 |

The six crosses represent a range of "typical" parental stocks that might be used by soybean breeders in similar maturity zones (IV-VI) of the Southeast. Two check cultivars, 'Forrest' and 'Essex', were included as a basis for comparison.

The experimental design was a randomized complete block with three replications per nursery site. Plot size consisted of 1 or 2 rows (Milan high-stress) and three rows (Milan low-stress, all years; and yield trials, 1985-1986) which were 6.10 m long with 0.92 m spacing between rows. Data taken consisted of seed yield and seed moisture content, maturity and plant height (KLS, PES, MES only), and lodging (PES and MES only).

Analyses of variance were conducted on yield to determine statistical differences among genotypes for individual year-location-sites. In addition, combined analyses of variance were conducted for low-stress sites and for high-stress sites combined across locations and years in order to determine statistical differences for yield

among years, locations, genotypes and their interactions (16, 36). Year and location were designated as fixed effects making the model mixed. Finally, using a completely random model, analyses of variance across each year and when combined were conducted on yield in order to determine statistical differences among years, locations, genotypes and their interactions.

The yield stability of each soybean line was determined by regressing the individual line's mean yield at a site on the site mean (yield of all lines) across sites, locations, and years (11). The Statistical Analysis System (SAS) (32) was utilized for above analyses.

The 48 soybean lines were ranked from highest to lowest based on their mean yield over four years, all nursery sites and yield trial locations (1986 MTLS excluded) for the purpose of simulating truncated selection. Selection intensities of 33% and 20% were used in order to simulate the selection intensity that soybean breeders might use at preliminary yield testing stages. This ranking provided the bases by which the lines were separated into superior and non-superior groups. Relative rankings of the mean yield of all lines were made for each year and combinations of years (2 and 3 year combinations) for individual sites, location, and their combinations. Finally, the percentages of the superior lines which would have been selected in each of the previously mentioned year-location-site combinations were calculated. Since the percent data ranged from 0 to 100%, an arc sine transformation was conducted prior to running analyses of variance and Duncan's Multiple Range Tests on the data (18). The rankings,

percentages and mean separations provided the bases for comparing simulated selection for yield in the low-versus high-stress environments. SAS (32) was utilized for these analyses.

# CHAPTER 3

# RESULTS AND DISCUSSION

## Soil Characteristics of High- and Low-Stress Nursery Environments

Several soil parameters (physical and chemical) were measured on the high- and the low-stress sites at both locations. A summary of the results are presented in Tables 3 and 4. In addition, the nursery site mean yields (average of all genotypes across years) are presented in Table 3 for each site at each location. The site mean yields illustrate the magnitude of differences in productivity of the low- versus high-stress sites at each location. The mean yield of the low-stress nursery at the Milan location was approximately four times greater than the high-stress nursery (2.71 vs 0.74, Mg $ha^{-1}$ respectively) and four times greater at the Plateau location (2.00 vs. 0.50 Mg $ha^{-1}$, respectively, Table 3).

Results from soil classification show soil type differences within and between locations for nursery environments (Table 3). More extensive description and classification are shown in Tables A1-A9 of the Appendix. Bulk density (BD) showed no significant differences among soil levels within Plateau and Milan low-stress nursery sites while their high-stress nursery sites surface layers (0-12.7 cm) were significantly ($P \leq 0.05$) different (Table 3). Percent of total root mass among soil levels at all nursery sites showed approximately

Table 3. Site mean yield of soybean lines, soil bulk density, and percent root mass for Plateau and Milan low- and high-stress nursery environments.

| Characteristic | Plateau | | Milan | |
|---|---|---|---|---|
| | LS* | HS* | LS | HS |
| | ----------Mg ha$^{-1}$---------- | | | |
| Yield+ | 2.00±0.04 | 0.50±0.02 | 2.71±0.05 | 0.74±0.02 |
| | ----------Mg m$^{-3}$---------- | | | |
| Bulk Density | | | | |
| 0-12.7 cm | 1.50a§ | 1.30a | 1.50a | 1.30b |
| 12.8-25.4 cm | 1.60a | 1.50a | 1.60a | 1.50a |
| 25.5-38.1 cm | 1.70a | 1.60a | 1.60a | 1.50a |
| | ----------g cm$^{-3}$---------- | | | |
| Root Weight | 0.513a§ | 0.190a | 0.480a | 0.328a |
| 0-12.7 cm | 77%** | 89% | 82% | 88% |
| | 0.120b | 0.014b | 0.097ab | 0.036b |
| 12.8-25.4 cm | 18% | 7% | 17% | 10% |
| | 0.030b | 0.009b | 0.007b | 0.007b |
| 25.5-38.1 cm | 5% | 4% | 1% | 2% |
| Soil Classification | Typic Hapludult | Aquic & Typic Hapludult | Aquic Udifluvent | Aquic & Glossic Fragiudalf |

+Includes 50 soybean lines over 4 years and 3 replications per year.

*LS = Low-stress nursery sites. HS = high-stress nursery sites.

§Values followed by a common letter are not significantly different ($P \leq 0.05$) with comparisons only within nursery sites.

**Percent of total root weight.

Table 4. Mean chemical parameters for surface and subsoil layers at Plateau and Milan low- and high-stress nursery environments.

| Soil Parameters | Plateau | | | | Milan | | | |
|---|---|---|---|---|---|---|---|---|
| | Low-Stress | | High-Stress | | Low-Stress | | High-Stress | |
| **Surface Layer** | | | | | | | | |
| pH | -- | 5.8 | -- | 4.8 | -- | 6.4 | -- | 5.0 |
| C(%) | -- | 1.1 | -- | 2.2 | -- | 0.5 | -- | 0.6 |
| | $\mu g^{-1}$ | % sat | $\mu g\ g^{-1}$ | % sat | $\mu g\ g^{-1}$ | % sat | $\mu g\ g^{-1}$ | % sat+ |
| P | 18.30 | -- | 13.60 | -- | 16.30 | -- | 11.00 | -- |
| Al | 2.45 | 2.8 | 20.45 | 57.8 | 0.37 | 0.4 | 12.69 | 28.7 |
| Mn | 0.50 | 0.1 | 0.33 | 0.9 | 0.09 | 0.1 | 0.81 | 1.5 |
| Ca | 73.13 | 82.1 | 7.81 | 22.1 | 74.47 | 79.7 | 35.88 | 49.6 |
| Mg | 3.46 | 3.9 | 0.57 | 1.6 | 8.33 | 9.0 | 6.35 | 11.2 |
| K | 9.86 | 11.1 | 6.24 | 17.6 | 10.19 | 10.9 | 5.02 | 9.1 |
| **Subsoil Layer** | | | | | | | | |
| pH | -- | 5.2 | -- | 4.8 | -- | 5.9 | -- | 4.9 |
| C | -- | 0.3 | -- | 0.5 | -- | 0.4 | -- | 0.2 |
| P | 3.20 | -- | 4.80 | -- | 11.10 | -- | 9.90 | -- |
| Al | 22.60 | 32.6 | 29.48 | 76.4 | 0.64 | 0.7 | 32.23 | 48.0 |
| Mn | 0.40 | 0.1 | 0.13 | 0.3 | 0.07 | 0.1 | 0.63 | 0.9 |
| Ca | 39.70 | 57.2 | 3.94 | 10.2 | 77.79 | 81.9 | 22.92 | 29.6 |
| Mg | 2.34 | 3.4 | 0.60 | 1.6 | 10.60 | 11.1 | 11.35 | 15.6 |
| K | 4.70 | 6.8 | 4.45 | 11.5 | 5.77 | 6.2 | 4.25 | 6.0 |

+% saturation based on n=30; concentrations for Al, Mn, and Ca based on n=78.

83 percent of the toal root mass found in the surface layer (0-12.7 cm) and significant differences ($P \leq 0.05$) among the other two soil levels (Table 3). The surface BD range (1.30-1.50 g $cm^{-3}$)containing the greatest percent of total root mass was found to be in a normal surface BD range of 1.00-1.60 g $cm^{-3}$ (4) indicating that no physical barriers existed (plow-pan or fragipan) to soybean root penetration into the subsoil.

Soil pH values for nursery environments were different within and between for both surface ( 13cm soil depth) and subsoil ( 13-50cm) layers except Plateau high-stress soil layers (Table 4). Acidity was highest in high stress (pH range = 4.8-5.0) and lowest in low-stress (pH range = 5.2-6.4). The percent aluminum (Al) saturations were much greater ( $\approx$25 times) in high-stress versus low-stress nursery environments while calcium saturations were greater ( 3 times) in low-stress nursery environments, as would be expected (Table 4). The Al and Ca saturation differences contribute to the pH differences and supports findings by Huett and Menary (20)in which calcium in nutrient solution (500 g $\mu g^{-1}$) completely overcame the detrimental effect of Al on yields of cabbage, lettuce, and kikuyu grass.

The phosphorus (P) as well as the potassium (K) concentration were similar between locations and nursery environments in the surface layer (plow layer) but did differ between locations for the subsoil layer (Table 4). The percent magnesium (Mg) saturations were variable within and between locations for the nursery environments (Table 4). The percent manganese (Mn) saturations were at sufficiently low concentration levels (0.1 to 1.5%) to cause no detrimental effect on

seed yield (Table 4). The organic matter (C%) levels at each of the sites were in the range (0.2 to 2.2%) of that found in mineral soils typically throughout Tennessee (2.2%, Table 4). The highest organic matter was found in the surface layers at the Plateau location (Table 4). Overall, the primary factors for reduced yields between low- and high-stress nursery environments were high aluminum concentrations and reduced availability of P, K, Ca, and Mg. These findings were similar to those reported by Foy (14), Kamprath and Foy (22), and Sartain and Kamprath (31) for acid soil conditions in other states.

## Analyses of Variance

Nursery Environments: This research was conducted over five growing seasons (1982-1986). The 1983 growing season was a severe drought season; therefore, the data collected in 1983 have been excluded from all the analyses. The data from the low- and high-stress nursery environments at both locations (Plateau and Milan) were analyzed by individual year and then by type of nursery site combined over years and locations to determine the effects of year, location, and their interactions on yield of the soybean lines.

Analyses of variance for low-stress nursery environments showed significant ($P \leq 0.01$) differences among genotypes at each location each year (Table 5). Analyses of the high-stress nursery environments revealed that there were predominately no significant differences among genotypes at each location each year with the exception of Plateau in 1982 and Milan in 1986 (Table 5). All genotypic mean squares for low-stress sites were 2 to 40 times greater in magnitude compared to high-

stress sites, which reflects the smaller magnitude of differences among the mean performance of the soybean lines in the high-stress environments (Table 5).

The individual year-nursery environment ANOVAs indicate that genotypes do respond differently under different environmental and cultural conditions. The findings of a greater genotypic variance in low-stress compared to high-stress environments is in agreement with the findings of Johnson and Frey (21) that genotypic and environmental variances increased as the environmental stresses were reduced.

Analyses of variance for combined low- and combined high-stress nursery environments showed significant ($P \leq 0.01$) differences for all sources of variation (Table 6). Results of the combined low-stress nursery environments showed the three-way interaction (GxYxL) was approximately 1/2 to 1/4 the magnitude of the two-way interactions (GxY and GxL, respectively), whereas, in the high-stress environments these components were approximately the same. The genotypic variances for both combined low- and combined high-stress nursery environments were significant ($P \leq 0.01$, Table 6). This indicates that there were significant differences in the mean yields of the soybean lines in both types of environments when averaged over year and locations. The magnitude of the mean squares for years and locations in the low-stress nurseries indicate that the location to location variation (MS=183.33) had a greater impact on yield than did the year to year variation (MS=41.92, Table 6). On the other hand, the locations and years had equal effects (MS=17.80 vs. 17.92, respectively) on yield in high-stress nurseries (Table 6).

Table 5. Mean squares from the four individual year analysis for seed yield of the 50 soybean lines grown in the low-stress and high-stress nursery environments at the Plateau and Milan locations.

| Source of Variation | df | Mean Square 1982 | 1984 | 1985 | 1986 |
|---|---|---|---|---|---|
| | | Plateau Low-Stress | | | |
| Genotype | 49 | 0.58** | 0.35** | 0.43** | 0.43** |
| Error | 98 | 0.17 | 0.13 | 0.03 | 0.08 |
| | | Plateau High-Stress | | | |
| Genotype | 49 | 0.25** | 0.02 | 0.01 | 0.01 |
| Error | 98 | 0.11 | 0.02 | 0.01 | 0.01 |
| | | Milan Low-Stress | | | |
| Genotype | 49 | 0.71** | 0.46** | 0.29** | 0.50** |
| Error | 98 | 0.29 | 0.22 | 0.15 | 0.26 |
| | | Milan High-Stress | | | |
| Genotype | 49 | 0.07 | 0.05 | 0.08** | 0.03 |
| Error | 98 | 0.06 | 0.04 | 0.07 | 0.02 |

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

Table 6. Mean squares from analyses of variance of seed yield of 50 soybean genotypes for combined low- and combined high-stress nursery environments over 4 years (1982, 1984, 1985 and 1986).

| Source of Variation | df | Mean Squares | |
|---|---|---|---|
| | | Low-Stress | High-Stress |
| (Y) Year+ | 3 | 41.92** | 17.92** |
| (L) Location+ | 1 | 183.33** | 17.80** |
| Y x L | 3 | 9.89** | 9.26** |
| (R) Replication/YxL(error a) | 16 | 1.34** | 0.53** |
| (G) Genotypes | 49 | 0.81** | 0.08** |
| G x Y | 147 | 0.42** | 0.06** |
| G x L | 49 | 0.82** | 0.07** |
| G x Y x L | 147 | 0.28** | 0.07** |
| Error b | 784 | 0.17 | 0.04 |

**significant at P 0.01

+Assumed to be fixed effects

Yield Trials: Five yield trials were conducted throughout the state in each of 1985 and 1986 to obtain pertinent information about yield and adaptability of the fifty soybean genotypes. The yield trial data from Middle Tennessee Experiment Station in 1986 was excluded from the ANOVA due to poor stands. The analysis of variance procedures for yield trials were based on a random effects model.

All sources of variation were significant ($P \leq 0.01$) when the genotypes were analyzed across locations each year as well as across years and locations (Table 7). As was true with the nursery environments, this indicates that there are significant differences among soybean lines with respect to their yield capacity in a range of environments so that it should be possible to select the "superior" lines from the group. There were significant ($P \leq 0.01$) differences in the mean productivity levels among the locations each year but not when combined across years (Table 7). However, the year x location interaction was significant indicating that mean productivity level at the five locations relative to each other was not the same in 1985 and 1986. As was expected, the GxE interactions (GxL, GxY, GxYxL) were significant indicating that the relative rankings of the soybean lines were not consistent across locations and years (Table 7). The inconsistency of relative ranking has important consequences in being able to separate the superior lines from non-superior lines.

Table 7. Mean squares from analyses of variance of seed yield of 50 soybean genotypes from yield tests grown at five locations in 1985, 1986, and combined across years.

| Source of Variation | Degress of Freedom | | | Mean Squares | | |
|---|---|---|---|---|---|---|
| | 1985 | 1986+ | 1985-1986 | 1985 | 1986 | 1985-1986 |
| (Y) Year | -- | -- | 1 | -- | -- | 46.73 |
| (L) Location | 4 | 3 | 3 | 19.21** | 116.99** | 28.80 |
| Y x L | -- | -- | 3 | -- | -- | 111.93** |
| (G) Genotype | 49 | 49 | 49 | 0.64** | 0.52** | 0.78** |
| G x Y | -- | -- | 49 | -- | -- | 0.36** |
| G x L | 196 | 147 | 147 | 0.24** | 0.20* | 0.27** |
| G x Y x L | -- | -- | 147 | -- | -- | 0.20** |

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

Degrees of freedom for error terms are calculated based on Satterthwaite's approximation for synthesized error terms.
+Middle Tennessee yield trial was excluded from ANOVA because of poor stands.

## Superior Versus Non-Superior Lines

Of the 30 yield test environments included in this study from 1982 through 1986, 10 tests were grown in low-stress nursery environments, 10 tests were grown in high-stress nursery environments, and 10 were yield trials (1985 and 1986). The mean yields for each of the 48 soybean lines and the 2 cultivars were calculated separately for each of the 30 environments (Table A-11 and A-12, Appendix).

The mean yield of each line averaged across all low-stress tests and the yield trials for four years was plotted against its mean yield averaged across all high-stress tests for four years (Figure 1). The graph was then divided into 4 quadrants; the dividing lines being the grand mean of all low-stress plus yield trial environments averaged across all soybean lines and years ($\bar{y}$ = 2.25 Mg ha$^{-1}$) and the grand mean of all high-stress nursery environments averaged across all soybean lines and years ($\bar{x}$ = 0.62 Mg ha$^{-1}$, Figure 1). The soybean lines falling in the upper right hand quadrant had mean yields which were above the grand mean for all low-stress plus yield trial environments as well as above the mean for all high-stress environments. These lines were deemed the most desirable lines for selection and were considered the "standard" superior genotypes for the bases of simulated selection.

## Simulated Selection

### Selection Intensity of 33%

From the results of the analyses of variance, a large amount of genotype x environment interaction (GxE) occurred, as was expected.

With the occurrence of such interactions, an important consideration in plant breeding is whether it is possible to select the superior genotypes from among a random group of lines in the early stages of yield testing by testing in only one type of environment.

Selection intensities that plant breeders often use in the early stages of yield testing (often referred to as preliminary yield tests) of experimental lines range from 20 to 33%. A selection intensity of 33% was used in the initial simulated selection comparisons in this study and later increased to 20 percent for comparative purposes.

The effectiveness of simulated selection for the top 16 (33%) and top 3 lines were based on various nursery environment-location-year combinations. The top 3 soybean lines (TN82-264, TN82-265, and TN82-268, Figure 1) were chosen because they had the highest mean yields of the superior group. Since their mean yields were very similar and not significantly ($P \leq 0.05$) different, selection of any one of them would have been satisfactory thus, they were treated as the "best of the best".

The above combinations were made by using: a) only low-stress (LS) nursery tests, b) only high-stress (HS) nursery tests, and c) low- plus high-stress (L+HS) nursery tests based on one year, two year, and three year combinations of testing. The year combinations were evaluated for individual locations and when locations were combined. The mean yield and rank of the 48 soybean lines were calculated for all of the combinations mentioned above. The rationale behind selecting the superior lines from these various nursery environment-location-year combinations was to simulate a plant

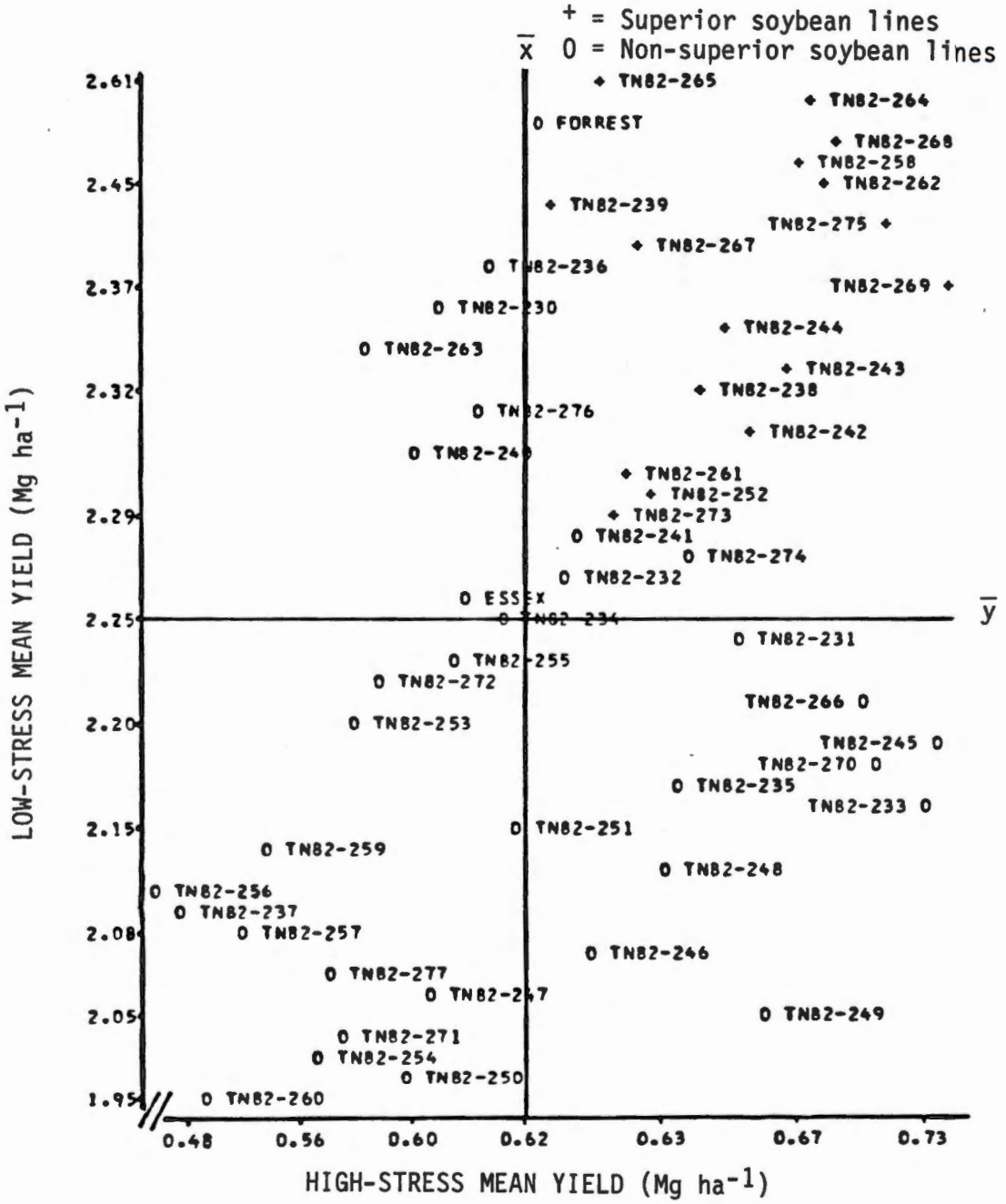



Figure 1. Scatter diagram of means for superior and non-superior soybean lines in low- versus high-stress nursery environments over four years (1982, 1984, 1985, and 1986).

breeder's approach to yield testing of experimental lines at early stages (preliminary) in low- versus high-stress nurseries at different locations to determine the most effective way of identifying the best lines. Counts were made to determine the percentage of the top 16 (33% selection intensity) lines which would have been selected in each of the nursery environment-location-year combinations outlined above.

Low- versus High-Stress Environments: The percentage of the 16 superior lines that would have been selected across all years of testing for low- versus high-stress nursery sites ranged from 47 to 73% for low-stress nurseries and 32 to 47% for high-stress nurseries. The combined LS sites over both locations across three years of testing had the highest percent (73%, 12 lines) while the lowest percent (32%, 5 lines) was found at Plateau HS site for one year of testing (Figure 2).

Comparisons among low- vs. high-stress environment combinations for percentages of 16 superior lines which would have been selected from one or two or three years of testing revealed that the various combinations were predominantly non-significant. Significant differences ($P \leq 0.05$) were found using Duncan's Multiple Range test with one year of testing at Plateau HS (32%) compared to one year of testing at Milan + Plateau LS (58%); compared to two years of testing at Plateau LS (55%) and Milan + Plateau LS (58%); and compared to three years of testing at Milan LS (60%) and Milan + Plateau LS (72%) (Figure 2). These findings indicate that certain low-stress sites combined over locations across 1, 2, or 3 years of testing were somewhat better nurseries for selecting a higher percentage of the superior lines (3-7)

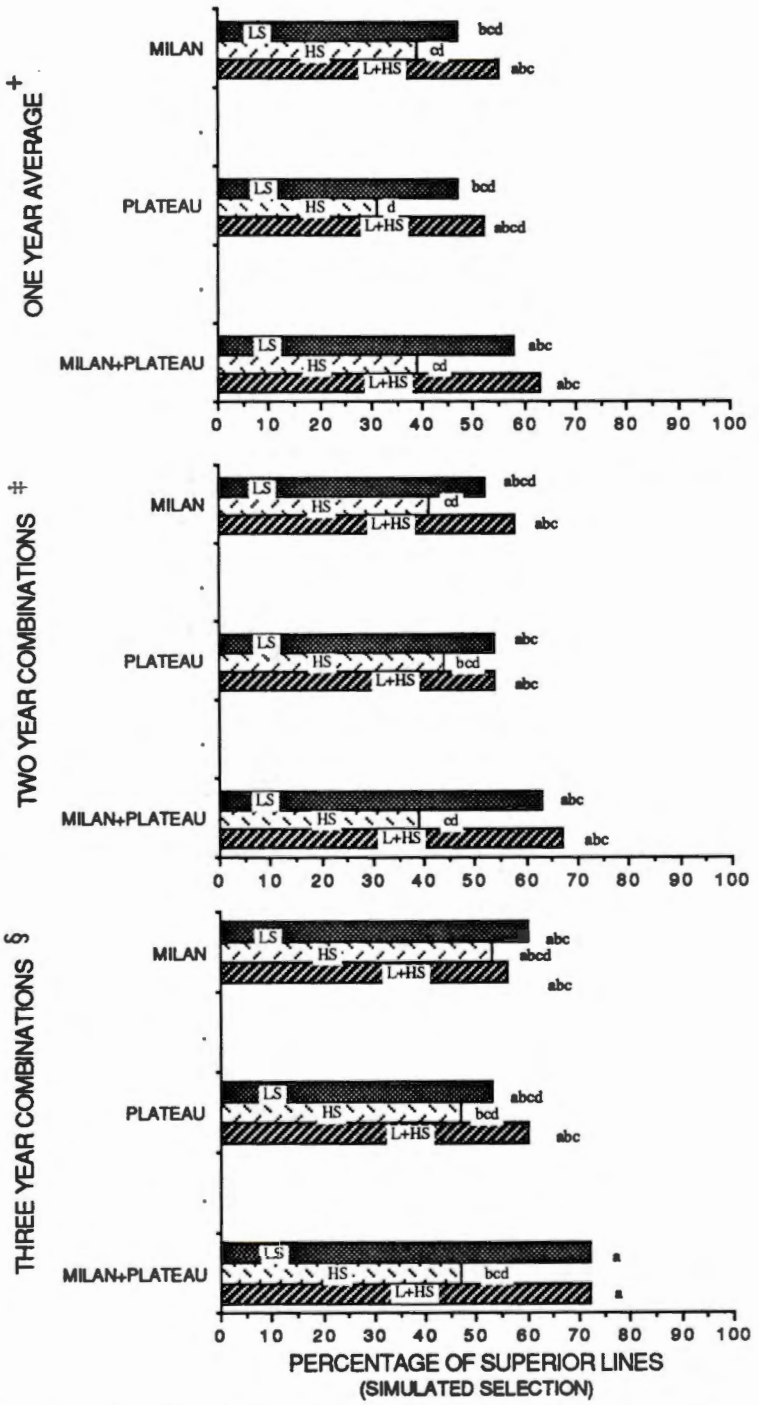



Figure 2. Comparison of the mean percentage of the 16 superior lines which would have been selected (simulated) using a selection intensity of 33% and only one, two, or three years of testing in low-stress (LS), high-stress (HS), or low- plus high-stress (L+HS) nursery environments at the Milan and Plateau locations. Bars followed by a common letter are not significantly different ($P < 0.05$). +=mean of 1982, 1984, 1985, 1986. ‡=mean of 1982 and 1984, 1984 and 1985, 1985 and 1986. §=mean of 1982, 1984, and 1985, and 1984, 1985, and 1986.

when compared to one year of testing at Plateau HS. However, the general trend indicated that either low- or high-stress nurseries would have led to similar results of selecting for the superior lines.

Low- plus High-Stress Environments: The minimum and maximum percentages of the top 16 lines that would have been selected by combining low- plus high-stress nursery sites were 53 and 73%, respectively. The highest percent (73%, 12 lines) would have occurred by combining L+HS sites over both locations across three years of testing while the lowest percent (53%, 8 lines) was at Plateau L+HS sites for one year of testing. The Duncan's Multiple Range test for mean separation among low- plus high-stress combinations revealed no significant differences for percent of 16 superior lines (Figure 2). These results indicate that effective selection could have been practiced for superior lines from combining low- and high-stress sites at one location per year. The percentage were not significantly different from that of selection based on performance over an increased number of locations and years. Overall the L+HS sites showed close similarities to the individual location low- or high-stress nurseries for effectiveness in selection of superior lines.

Locations: The percentages of the superior lines that would have been selected at individual locations ranged from 33% (Plateau HS, 1 yrs.) to 60% (Milan LS or Plateau L+HS, 3 yrs., Figure 2). When the locations were combined the lowest percent would have been for HS sites, 1 or 2 years (39%) and the highest percent would have been for L+HS sites, 3 years (73%, Figure 2).

Comparison of LS, HS, or L+HS sites between locations or when locations were combined for percent of top 16 lines showed no significant differences across 1, 2, and 3 years of testing. This indicates that an acceptable number of the superior lines (5 to 12 lines) could have been selected at either or both locations with either one, two, or three years of testing.

One, Two, or Three Years of Testing: The percent of superior lines that would have been selected with only one, two, or three years of testing ranged from 32 (Plateau LS) to 63% (Milan + Plateau L+HS), 39 (Milan + Plateau HS) to 67% (Milan + Plateau L+HS), or 47 (Milan + Plateau HS) to 73% (Milan + Plateau L+HS), respectively. The mean separations of the percentages of the top 16 lines that would have been selected in nursery site-location combinations within one, two, or three years of testing were predominantly non-significant. The significant ($P \leq 0.05$) differences occurred with one year of testing at Plateau HS (32%) compared to Milan L+HS (56%) and Milan + Plateau LS and L+HS sites (58 and 63%, respectively) and with three years of testing at Plateau or Milan + Plateau HS (47%) compared to Milan + Plateau LS and L+HS (73%) sites (Figure 2). The comparisons among one, two, or three years of testing indicate that selection for an acceptable number of the superior lines would have been possible with one year of testing compared to the same nursery site-location combinations across 2 to 3 years of testing.

Top Three Superior Lines

What a plant breeder is most interested in is the ability to select the "best" lines from the population. The top 3 lines in this research were TN82-265, TN82-264, and TN82-268 (Figure 1). The previously mentioned procedure for combining the various nursery environments-locations-years for the purpose of simulating selection for the 16 superior lines was also utilized for calculating the percentages of top 3 lines that would have been selected from each combination.

Low- versus High-Stress Environments: The percentages of top 3 lines that would have been selected in low- and high-stress nursery sites ranges from 55 to 84% for low-stress nurseries and 33 to 84% for high-stress nurseries (Figure 3). The combined LS or HS sites at Plateau over 3 years and over both locations across three years of testing had the highest percent (84%, 2+ lines). The lowest percent (33%, 1 line) would have occurred at Milan HS with one or two years of testing and at Milan + Plateau HS sites with one or three years of testing (Figure 3). The mean separation of the percentages of the top 3 lines from simulated selection in low- vs high-stress environments showed no significant ($P \leq 0.05$) differences among nursery environments (Figure 3). These findings indicate that effective selection for at least 1 of the best lines could be accomplished in either nursery type per location or nursery type over both locations with 1, 2, or three years of testing.

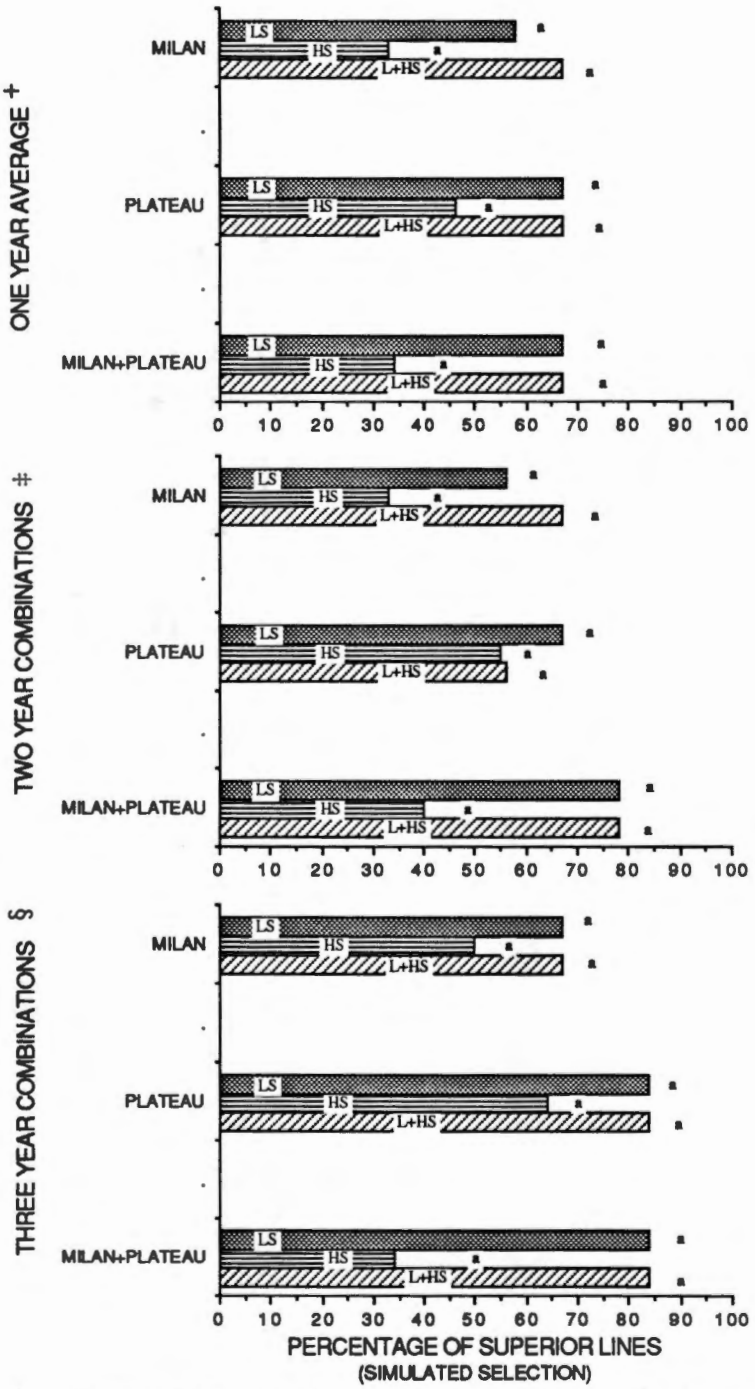



Figure 3. Comparison of the mean percentage of the top 3 superior lines which would have been selected (simulated) using a selection intensity of 33% and only one, two, or three years of testing in low-stress (LS), high-stress (HS), or low- plus high-stress (L+HS) nursery environments at the Milan and Plateau locations. Bars followed by a common letter are not significantly different ($P \leq 0.05$). +=mean of 1982, 1984, 1985, 1986. ‡=mean of 1982, 1984, 1984 and 1985, 1985 and 1986. §=mean of 1982, 1984, and 1985, and 1984, 1985, and 1986.

Low- plus High-Stress Environments: The percent of the top 3 lines that would have been selected by combining low- plus high-stress nursery sites ranged from 54 to 83%. The highest percent (83%, 2+ lines) was found at combined L+HS sites over both locations across three years of testing while the lowest percent (54%, ≈2 lines) was found at Plateau L+HS sites across three years of testing (Figure 3). Comparison among the various combinations of low- plus high-stress environments revealed no significant differences for percentages of the 3 superior lines (Figure 3). These results indicate that 2 nursery sites at either location could have resulted in at least two of the best lines being selected with either 1, 2, or 3 years of testing compared to basically the same results from one type of nursery site combined over two locations with 1, 2, or 3 years of testing. Overall, low- plus high-stress nurseries were no better than individual nursery types in their effectiveness of selecting for top 3 lines.

Locations: Simulated selection percentages of the 3 superior lines that would have been selected at individual locations and when locations were combined ranged from 33 to 84% (Figure 3). The highest percent (84%, 2+ lines) were found at Plateau LS and HS, and Milan + Plateau LS sites across three years of testing while the lowest percent (33%, 1 line) would have occurred at Milan HS site with one or two years of testing (Figure 3). The mean separation among locations and their combinations for percent of the top 3 lines revealed no significant differences (Figure 3). Therefore, selection could have been carried out at either location and at least 1 of the top 3 lines would have been selected from one, two, or three years of testing in

either type of nursery environment. There were no statistical differences between the effectiveness in selecting for acceptable numbers of the top 3 lines per location or when locations were combined.

One, Two, or Three Years of Testing: The percent of the top 3 lines that would have been selected across one, two, or three years of testing ranged from 33 to 63%, 33 to 78%, or 34 to 84%, respectively (Figure 3). The mean separation of these percentages revealed that there were no significant ($P \leq 0.05$) differences (Figure 3). These results indicate that at least 1 of the best lines could have been selected with only one year of testing using any of the nursery site-location combinations.

Overall, the simulated selection for the top sixteen and the top three soybean lines demonstrated that 32 to 58% (5-9 of 16 lines) and 33 to 67% (1-2 of 3 lines), respectively, of the superior lines ranked in the top one-third when one test was conducted at one location in one year at either a low- or high-stress nursery site. Increasing the number of years and combinations of sites would have increased the effectiveness some but not sufficient to warrant the extra labor and expense for preliminary testing. Furthermore, at least one of the top 3 lines ranked in the top one-third in every case so that the "best" line would have been saved regardless of the type of nursery environment(s), location(s), or year(s) used for testing. This indicates that it is not necessary to establish and maintain yield test sites which have acid soils that are low in fertility for the purpose of selecting soybean lines that perform well relative to others under

these conditions. It appears that the lines which had the best combinations of favorable genes for yield in high-productivity environments also had the best combinations of genes, relative to the other lines, for superior yield in stress environments; where the stresses were due to climate and soil fertility factors. Therefore, the range of soil and climatic conditions encountered in normal yield trial environments should be adequate for separating the highest yielding group of soybean lines (e.g. top one-third) from the lower yielding lines (e.g. bottom two thirds) in early yield testing stages and have a high probability that the "best" line is included in the top group. This means that soybean breeders can conserve time, resources, and labor at the preliminary yield testing stage by selecting the superior lines in high-productivity environments and expect them to be the superior performers in low-productivity environments, or vice versa. The distinguishing of differences among the top group of lines (i.e. best of the best) requires tests at more locations over more years.

These results are similar to what Panter (27) reported on double-crop versus conventional soybean yield tests. He concluded that selection of the lines based on mean performance in either conventional or double-crop tests in various year-location-nursery type combinations produced up to 65% of the superior lines as well as the best soybean lines, indicating no immediate need to maintain separate selection nurseries.

Simulated Selection Comparisons Between 33 and 20% Selection Intensities

Thirty-three percent selection intensity (1/3 of the population) is often used at the preliminary yield testing stage, but it may be desirable to increase the selection intensity for the purpose of increasing the expected genetic gain from selection ($\Delta G$) as well as reducing costs by having fewer lines in subsequent tests. For the study reported herein, a second selection intensity of 20% was chosen in order to compare results from simulated selection using 20% versus 33% selection intensities. Thus, instead of choosing 16 soybean lines (33% selection intensity) only 10 lines were classified as superior with the top 3 superior lines remaining the same. The percentage calculations, based on 20% selection intensity, were performed in the same manner as previously discussed for 33% selection intensity.

Locations: The percent of top 16 and 10 lines that would have been selected at Milan, Plateau, and Milan + Plateau locations over one year of testing for low-stress, high-stress, and when combined revealed ranges of 32 to 64% and 20 to 44%, respectively. The lowest and highest number of lines for 33% selection intensity (5-10 lines, respectively) occurred at Plateau HS and Milan + Plateau L+HS sites, respectively while lowest and highest number of lines for 20% selection intensity (2-4 lines) occurred at Milan and Plateau HS and Milan + Plateau L+HS site, respectively (Figure 4). Mean separation of the percentages between the selection intensities within and between locations and when combined for LS, HS, and L+HS sites revealed significant ($P \leq 0.05$) differences (Figure 4). Also,

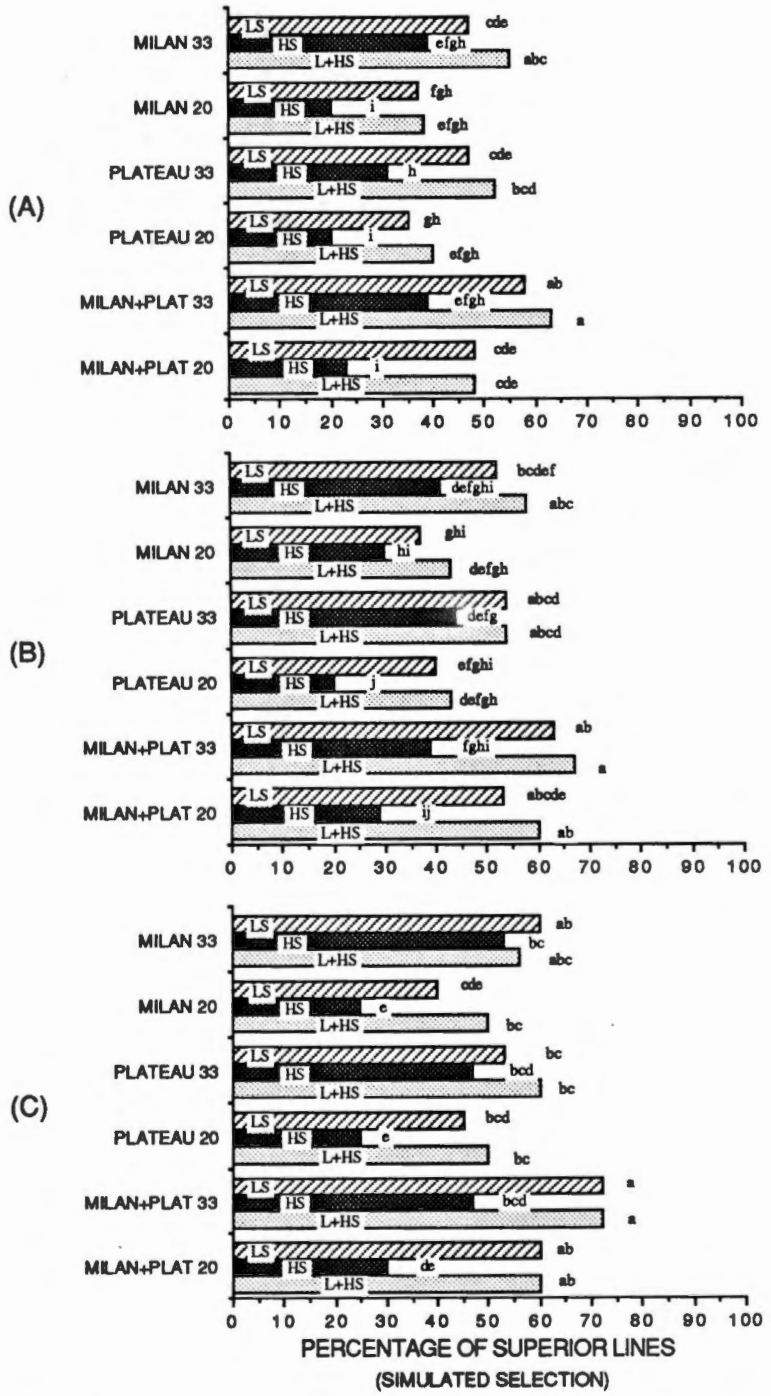



Figure 4. Comparison between 33% (top 16) and 20% (top 10) selection intensities for the percentage of the superior lines which would have been selected (simulated) for one (A), two (B), and three (C) years of testing in low-stress (LS), high-stress (HS), or low- plus high-stress (L+HS) nursery environments at Milan and Plateau locations. Bars followed by a common letter are not significantly different ($P \leq 0.05$). Comparisons are appropriate only within one, two, or three years of testing and not among these year combinations.

significant ($P \leq 0.05$) differences occurred among LS, HS, and L+HS sites at each location and when locations were combined when only 20% selection intensity was considered (Figure 4). These findings indicate that the 20% selection intensity would have been too intense because a smaller percentage of the top 10 would have been identified compared to the percentage of top 16 for 33% intensity.

Simulated selection based on individual and combined location-nursery site combinations across two years of testing using 33 versus 20% selection intensity revealed ranges of 39 (6 lines) to 67% (11 lines) for the less intense selection and 20 (2 lines) to 60% (6 lines)for the more intense selection. The lowest and highest percentages for 33% selection intensity occurred at Milan + Plateau HS sites and Milan + Plateau L+HS sites, respectively whereas the low and high percents for 20% selection intensity were observed at Plateau HS and Milan + Plateau L+HS sites, respectively (Figure 4).

The mean separations between the selection intensities within locations and when locations were combined for nursery site(s) revealed a predominance of significant ($P \leq 0.05$) differences (Figure 4). Comparisons of the same location-nursery site combinations for 20% selection intensity were generally non-significant (Figure 4). Results from location comparisons between both selection intensities across two years of testing generally indicated a more effective selection with 33% versus 20% selection intensity at each location and nursery site.

The ranges for percentages of superior lines that would have been selected at individual and combined location-nursery site combinations

with three years of testing between 33 and 20% selection intensities were 47 (8 lines) to 73% (12 lines) and 25 (3 lines) to 60% (6 lines), respectively. The minimum and maximum percents of superior lines for 33% selection intensity occurred at both location HS sites and Milan + Plateau LS and L+HS sites, respectively. The low and high percents for 20% selection intensity occurred at the same location-nursery site combinations (Figure 4). The mean separation among 3-year mean percentages between both selection intensities for location-nursery type combinations revealed a predominance of non-significant differences, but the individual location comparisons for high-stress sites were significantly ($P \leq 0.05$) different (Figure 4). The comparisons between locations-nursery type combinations also revealed a predominance of non-significant differences (Figure 4). These findings indicate that preliminary yield testing over a period of three years would probably be as effective in selecting acceptable numbers of superior lines based on 20% versus 33% selection intensity. However, with only one or two years of testing, a higher number of top lines would have been missed at each location if the selection intensity had been 20% compared to 33% at both locations (Figure 4).

One, Two, or Three Years of Testing: Simulated selection percents of the top 16 versus the top 10 lines that would have been selected over one year, two years or three years of testing for LS, HS, and L+HS sites at each location and when combined revealed the same magnitudes of percents which were observed for the location comparisons previously mentioned. The 20% selection intensity provided the lowest percentages, 20% (2 lines out of 10) for one year

of testing, 60% (6 lines out of 10) for three years of testing compared to percentages for 33% selection intensity of 32% (5 lines out of 16) for one year of testing, 73% (12 lines out of 16) for three years of testing (Figure 4). Mean separation was conducted within one, two, or three years of testing and not among year combinations. Significant ($P \leq 0.05$) differences were determined within one and within two years of testing for nursery site-location combinations while three years of testing showed predominantly no significant differences (Figure 4). A 33% selection intensity would have been more effective for identifying superior lines with one and two years of testing compared to the selection intensity of 20%; whereas, with three years of testing, both selection intensities would have led to similar results.

The general findings between 33 and 20% selection intensities for location and year combinations revealed a general trend of significant ($P \leq 0.05$) differences between and among nursery site combinations. Therefore, an important consideration is whether the opportunity for a breeder to identify the "best" line (top 3 lines in this study) is hindered by imposing a higher selection intensity of 20% compared to 33%.

Top Three Superior Lines

Location: The percentages of top 3 lines that would have been selected for 33 versus 20% selection intensity across location(s) for one year of testing showed ranges of 33 (1 line) to 67% (2 lines) and 17 (<1 line) to 58% (2 lines), respectively (Figure 5). Comparisons

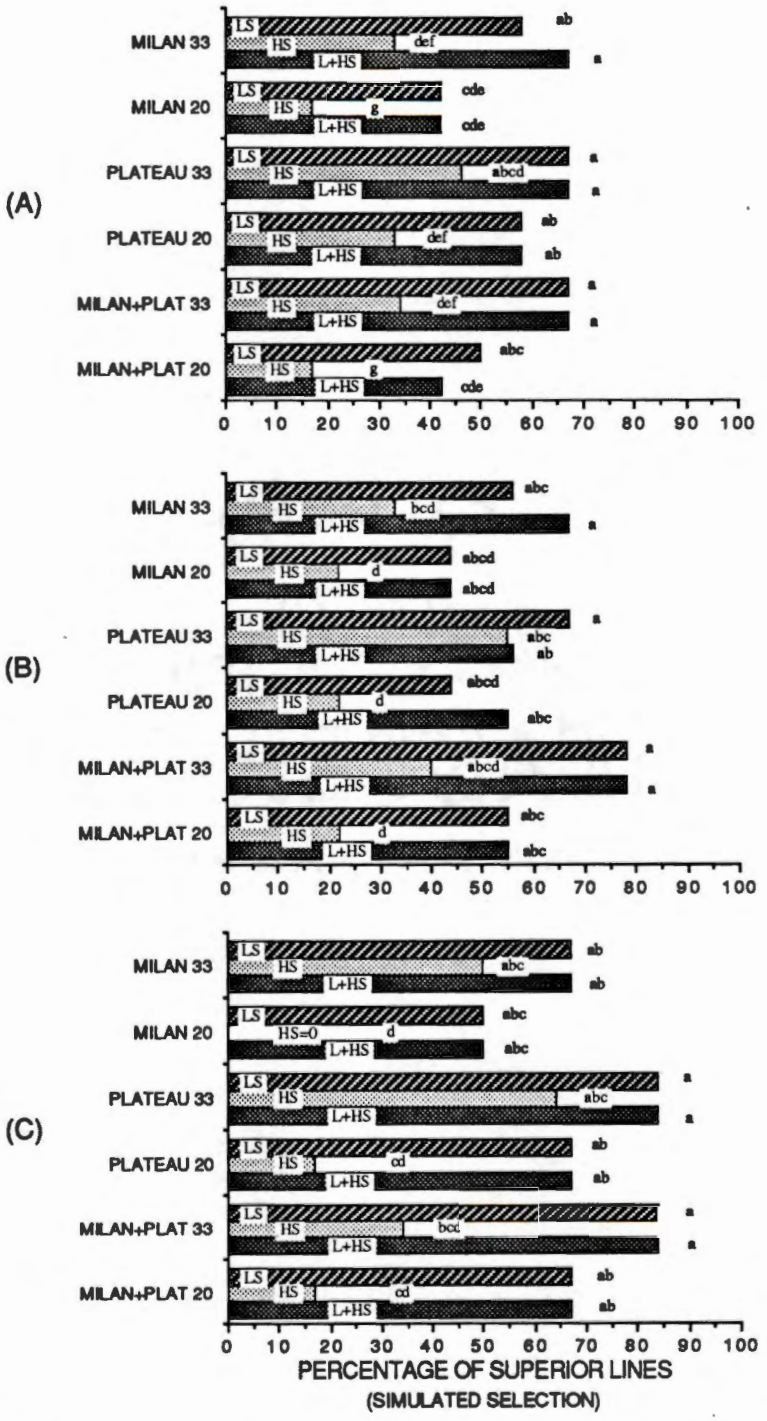



Figure 5. Comparisons between 33% and 20% selection intensities for the top 3 superior lines which would have been selected (simluated) for one (A), two (B), and three (C) years of testing in low-stress (LS), high-stress (HS), or low- plus high-stress (L+HS) nursery environments at Milan and Plateau locations. Bars followed by a common letter are not significantly different ($P \leq 0.05$). Comparisons are appropriate only within one, two, or three years of testing and not among these year combinations.

between both selection intensities within and among locations revealed significant ($P \leq 0.05$) differences among most of the nursery sites and their combinations (Figure 5). These results indicate that there was a higher probability at each location of identifying at least 1 of the top 3 lines using 33% selection intensity relative to the probability of successfully identifying 1 of 3 using 20% selection intensity.

Simulated selection for the best lines using a selection intensity of 33% versus 20% across locations for two or three years of testing showed ranges of 33 (1 line) to 78% (≈2 lines) versus 22 (≈1 line) to 56% (≈2 lines) for two years of testing and 34 (1 line) to 84% (2+ lines) versus 0 (no lines) to 63% ( 2 lines) for three years of testing (Figure 5).

Comparisons within and between locations(s) across two or three years of testing were generally non-significant among nursery sites and their combinations. However, if comparisons for 20% selection intensity at Milan, Plateau, and Milan + Plateau HS sites are made with the same location(s) LS and L+HS sites then a predominant amount of significant ($P \leq 0.05$) differences were observed. The findings indicate a small number of statistical differences between both selection intensities at either location or when combined for nursery site(s).

<u>One, Two, or Three Years of Testing</u>: The percentages of the top 3 lines that would have been selected using 33 or 20% selection intensity with one year of testing revealed an overall range of 17 (for 20% selection intensity) to 67% (for 33% selection intensity, Figure 5). The mean separation between these selection intensities

with one year of testing revealed a predominance of significant ($P \leq 0.05$) differences among nursery site-location combinations with only one year of testing (Figure 5). A selection intensity of 33% would have been better than 20% for identifying an acceptable number of the top 3 lines.

The percentages of top 3 lines that would have been selected using 33 versus 20% selection intensities with two or three years of testing show ranges of 22 (for 20% selection intensity) to 78% (for 33% selection intensity) for two years of testing and 0 (for 20% selection intensity) to 84% (33% selection intensity) for three years of testing (Figure 5). Comparisons within the 2 or 3 years of testing revealed mostly non-significant differences between selection intensities among location(s) for the same nursery type (i.e. Milan 33 LS with Milan 20 LS; Plateau 33 LS . . . etc.). The significant ($P \leq 0.05$) differences that did occur were found with the 20% selection intensity at Milan, Plateau, and Milan + Plateau HS sites compared with most of the other LS or L+HS sites for 33%. These results also indicate a small number of statistical differences between both selection intensities at either location or when combined for nursery sites. In general, the trend for locations and nursery sites with one year of testing favored using thirty-three percent selection intensity compared to a higher intensity of twenty percent. However, the results indicate that increasing the number of locations, years, and nursery sites does improve the effectiveness when using a 20% selection intensity but the extra time, resources and expenses would not justify it. Overall, the chances would have been poor for obtaining at least

one of the best lines with one year of testing using a 20% selection intensity. A breeder is better advised to use the more relaxed selection intensity (33%) in preliminary yield testing than a more intense one (20%).

## Stability Analysis

### Stability Parameters of the Top, Middle, and Bottom Groups of Soybean Lines

Stability analyses were performed on combined nursery environments (low- plus high-stress) from the two locations over four years plus yield trial testing (1985 and 1986) to compare the regression coefficients and deviations from regression of the 16 superior soybean lines to the non-superior lines (middle 16 and bottom 16 lines). Using the regression technique of Eberhart and Russel (11), yield of each soybean line was regressed on site mean yield resulting in a regression coefficient and deviation from regression for each line. In order for a line to be classified as superior and stable it must have consistently performed above the test mean across various environments and have a regression coefficient of 1.00 or greater plus a minimum deviation from regression. Regression analysis is particularly effective in emphasizing the actual trend of varietal yield response to a range of natural environments (12). The two important indexes in regression analysis are the regression coefficient and values from regression. A regression coefficient of 1.00 indicates average stability, but when associated with high mean yield the varieties have general adaptability (12). On the other hand a regression coefficient of 0.00 or near zero produces varieties with low men yields which are

so stable (absolute phenotypic stability) they are insensitive to environmental change (12).

In this study genotypes with regression coefficients of 1.0 or greater and relatively low deviations from regression were considered stable because their yields increase proportionally with mean test yield. Lines which had regression coefficients less than 1.0 and relatively high deviations from regression, or both, were considered unstable because their yields did not increase proportionally with mean yield at a test site. Different genotypes may have similar slopes of their regression lines (i.e. b values), but their overall mean yield may be different; therefore, it is important to consider the overall mean yield along with the b value and deviation from regression in determining the worth of one line versus another.

Of the 16 lines making up the superior group which performed best in both low- and high-stress nursery environments (Figure 1), 10 lines (63%) had regression coefficients greater than 1.00 (Table A-13, Appendix). Nine (56%) of the middle non-superior lines had regression coefficients greater than 1.00. The bottom 16 non-superior lines only had four (35%) with regression coefficients greater than or equal to 1.00. Based on these percentages the superior lines, in general, had higher regression coefficients as well as higher yields compared to the non-superior lines. However, it does illustrate that there were non-superior lines which had rates of response to environmental changes which were similar to superior lines, but their yield potential was not as great.

Comparison of the regression coefficients among the 16 superior lines revealed that the b values of 15 (94%) of the lines were not different (Table A-13, Appendix). Also, out of the remaining 32 non-superior lines, the middle 16 lines' regression coefficients predominantly showed no differences from the top 16 superior lines; whereas, the bottom 16 were predominantly different from the top 16 (Table A-13, Appendix).

To determine if the regression values of the non-superior lines, as a group, were significantly different from the superior group, a mean separation for a data set of only regression values among the means of the top, middle, and bottom groups was performed (Table 8). The results revealed non-significant differences between the top and middle groups while the bottom group was significantly different ($P \leq 0.0$) from the top and middle 16 groups (Table 8). The regression coefficients for two of the top 3 superior lines (TN82-264, b=1.16 and TN82-268, b=1.0) showed no difference between their mean regression coefficients and the regression value of the top 16 group; whereas, TN82-265 had a regression coefficient (b=1.20) which was significantly higher than the top 16 group (Table 8). The regression coefficients of the top 3 lines were not significantly different (Table 8).

These results indicate that the superior lines were the ones that generally had the greatest yield response to changes in environmental conditions which influenced yield. Therefore, they were "stable" in the sense that they ranked in the top group regardless of the productivity level of the environment. Even in the high-stress

Table 8. Mean yield, regression coefficient, and deviation from regression of the top 3 soybean lines and the top, middle and bottom groups of 16 soybeans across all nursery environments and yield trials (1982, 1984, 1985, and 1986).

| Breeding Lines/ Groups | Yield | Regression Coefficient | Deviation from Regression |
|---|---|---|---|
| Top 3 lines | | | |
| TN82-265 | 2.00 | 1.20a[+] | 0.06 |
| TN82-264 | 1.99 | 1.16ab | 0.08 |
| TN82-268 | 1.94 | 1.10ab | 0.21 |
| Top 16 | | | |
| Mean | 1.86 | 1.04b | 0.10 |
| Range | (1.78-2.00) | (0.91-1.20) | (0.04-1.21) |
| Middle 16 | | | |
| Mean | 1.76 | 1.00b | 0.07 |
| Range | (1.71-1.83) | (0.90-1.10) | (0.03-0.19) |
| Bottom 16 | | | |
| Mean | 1.61 | 0.95c | 0.07 |
| Range | (1.50-1.71) | (0.87-1.03) | (0.02-0.12) |

[+]Values followed by a common letter are not significantly different at $P \leq .05$.

environments, their mean yields were lower, but, relative to the other lines, they were among the higher yielding ones.

Comparisons Among Crosses

After determining which of the 48 lines were the superior ones, the next logical step was to determine whether the crosses (mean of the group of eight lines) were similar in performance and stability. The pedigree, mean yield, b value, and deviation from regression for each of the six crosses are presented in Table 9.

Eleven (69%) of the 16 superior lines were from two crosses; six lines from the cross, Essex x (Bay x N73-520), and five lines from the cross, Essex x Hodgson, (Table 10). The remaining five genotypes (31%) came from three other pedigrees (Centennial x J74-45;J74-40 x Ts72-824, and J74-45 x Ts72-824). From the stability analysis of each line within each pedigree, five of the lines (including the top 3 superior lines) from the cross, Essex x (Bay x N73-520), had regression coefficients greater than 1.00 (Table A13, Appendix).

Mean separation was performed on the seed yield values of the six crosses plus both checks (Essex and Forrest) to determine which of the pedigrees had the highest yield (Table 9). Two of the crosses, Essex x (Bay x N73-520) and Essex x Hodgson, were not significantly ($P \leq 0.05$) different from the check cultivar, Forrest. Mean separation of the regression coefficients for the six crosses plus the two checks revealed no significant differences among Forrest, Essex x (Bay x N73-520), and Centennial x J74-45, while the remaining 4 crosses and the check cultivar, Essex, were significantly ($P \leq 0.05$) different from

Table 9. Mean yield, regression coefficient and deviation from regression of six soybean crosses (Pedigree) and two check cultivars across all nursery environments and yield trials (1982, 1984, 1985, and 1986).

| Pedigree | Yield | Regression Coefficient | Deviation from Regression |
|---|---|---|---|
| Essex x (Bay x N73-520)+ | 1.89ab* | 1.08a* | 0.09 |
| Essex x Hodgson | 1.80abc | 0.97c | 0.08 |
| Essex x (Forrest x OK963) | 1.74bc | 0.98bc | 0.06 |
| Centennial x J74-45 | 1.73bc | 1.04ab | 0.11 |
| J74-40 x Ts72-824 | 1.67c | 0.99bc | 0.06 |
| J74-45 x Ts72-824 | 1.65c | 0.94c | 0.05 |
| Check Cultivar | | | |
| Essex | 1.75bc | 0.99bc | 0.06 |
| Forrest | 1.92a | 1.14a | 0.08 |

+Top 3 lines

*Values followed by a common letter are not significantly different at $P \leq 0.05$ from 1

Table 10. Mean height, maturity, and yield for low- and high-stress nursery environments over two years (1984 and 85) for 16 superior lines.

| Soybean Lines | Pedigree | Low-Stress Ht. | Low-Stress Mat. | Low-Stress Yield | High Stress Ht. | High Stress Mat. | High Stress Yield |
|---|---|---|---|---|---|---|---|
| | | cm | days+ | Mg ha$^{-1}$ | cm | days+ | Mg ha$^{-1}$ |
| Superior Lines | | | | | | | |
| TN82-265 | Essex x (Bay x N73-520) | 95 | 41 | 2.4 | 51 | 37 | 0.6 |
| TN82-264 | Essex x (Bay x N73-520) | 81 | 30 | 2.2 | 44 | 24 | 0.5 |
| TN82-268 | Essex x (Bay x N73-520) | 78 | 25 | 1.9 | 41 | 22 | 0.5 |
| TN82-258 | J74-40 x Ts72-824 | 84 | 39 | 2.4 | 48 | 38 | 0.6 |
| TN82-262 | Essex x (Bay x N73-520) | 91 | 35 | 2.1 | 48 | 29 | 0.5 |
| TN82-275 | Centennial x J74-45 | 101 | 50 | 2.3 | 54 | 39 | 0.6 |
| TN82-239 | Essex x Hodgson | 95 | 33 | 2.5 | 46 | 30 | 0.6 |
| TN82-269 | Essex x (Bay x N73-520) | 77 | 25 | 2.2 | 44 | 23 | 0.5 |
| TN82-267 | Essex x (Bay x N73-520) | 95 | 36 | 2.0 | 50 | 35 | 0.5 |
| TN82-273 | Centennial x J74-45 | 103 | 44 | 2.1 | 52 | 40 | 0.4 |
| TN82-244 | Essex x Hodgson | 91 | 31 | 2.0 | 50 | 31 | 0.7 |
| TN82-243 | Essex x Hodgson | 92 | 30 | 2.3 | 53 | 32 | 0.6 |
| TN82-242 | Essex x Hodgson | 90 | 25 | 2.2 | 50 | 24 | 0.6 |
| TN82-238 | Essex x Hodgson | 90 | 32 | 2.4 | 52 | 31 | 0.5 |
| TN82-261 | J74-40 x Ts72-824 | 86 | 40 | 2.1 | 51 | 38 | 0.5 |
| TN82-252 | J74-45 x Ts72-824 | 97 | 34 | 2.1 | 55 | 28 | 0.7 |
| | Mean | 90 | 34 | 2.2 | 49 | 31 | 0.6 |
| | Range | 77-103 | 25-50 | 1.9-2.5 | 41-55 | 22-40 | 0.4-0.7 |
| Non-Superior Groups | | | | | | | |
| Middle & Bottom Groups | Mean | 92 | 37 | 2.1 | 53 | 34 | 0.6 |
| | Range | 78-117 | 30-49 | 1.8-2.5 | 46-61 | 25-42 | 0.4-0.7 |
| Check Cultivars | | | | | | | |
| Essex | | 76 | 31 | 2.0 | 42 | 31 | 0.5 |
| Forrest | | 90 | 36 | 2.2 | 58 | 34 | 0.5 |

+Days after August 31

Forrest and the three way cross previously mentioned. The mean yield and regression coefficient of the cross Essex x (Bay x N73-520) were the highest among the six crosses ($\bar{x}$ = 1.89 Mg ha$^{-1}$ and b = 1.08 Mg ha$^{-1}$, Table 9).

The fact that 69% of the superior lines (11 of 16) came from two crosses and that 84% of the non-superior lines (27 of 32) came from the other four crosses, illustrates that some cross combinations produce higher frequencies of lines with more favorable genes than do other crosses. A method that would discriminate among predicted cross mean performance levels for various cross combinations prior to crossing would increase the breeder's effectiveness of making those crosses which have the highest probability of superior lines. It appears that the lines within, as well as among, crosses that had the highest numbers of favorable genes could be distinguished from those with fewer favorable genes regardless of the type of environment in which they were tested.

## Analyses of Other Agronomic Characters

Comparison of the mean plant heights and maturities for the 16 superior lines with the means and ranges of the non-superior group over two years (1984 and 1985) in low- and high-stress nursery environments are shown in Table 10. The same characteristics for each of the 48 lines and check cultivars are shown in Table A-14 (Appendix). The objective of these analyses was to ascertain whether selecting for the highest yielding lines would lead to lines that were

taller and later, or shorter and earlier, etc., compared to the lower yielding lines.

Height and maturity ranges at low- and high-stress sites revealed no major differences among superior, non-superior, and check cultivars (Table 10). Comparison between the superior and non-superior groups for mean height and maturity within low-stress (90 vs 92 cm and 34 vs 37 days, respectively) and within high-stress sites (49 vs. 53 cm and 31 vs 34 days, respectively) showed small differences (Table 10). Comparison between the superior groups and check cultivars (Essex and Forrest) for mean height and maturity also revealed similar values. The superior group contained soybean lines which would be classified as either maturity Group IV, V, or VI as well as a range in plant heights similar to the check cultivars and lines within the non-superior group. Thus, selection for highest yield was a result of indirect selection for maturity or plant height.

Comparing mean heights and maturities of the top 3 lines revealed that they too were different in maturity and plant height (Table 11). TN82-264 and TN82-268 were approximately 15 and 8 cm, respectively shorter in stature and matured approximately 14 days earlier than TN82-265 in both low- and high-stress nursery environments.

As expected, the mean plant height for all groups (top, middle, bottom) were greater (≃2 times) in low-stress versus high-stress nurseries (Table 11). In general, it took approximately 3 additional days for lines to mature in low-stress compared to high-stress nurseries (Table 11).

Table 11. Mean height and maturity for the top, middle, and bottom group of 16 soybean lines in low- versus high-stress nursery environments (1984, 1985).

| Soybean Lines | Nursery Environment | | | |
|---|---|---|---|---|
| | Low-Stress | | High-Stress | |
| | Height | Maturity | Height | Maturity |
| | cm | days+ | cm | days+ |
| Top Group | | | | |
| Mean | 90 | 34 | 49 | 32 |
| Range | 77-103 | 25-30 | 41-55 | 22-40 |
| Middle Group | | | | |
| Mean | 92 | 36 | 53 | 34 |
| Range | 86-107 | 30-49 | 46-61 | 27-42 |
| Bottom Group | | | | |
| Mean | 92 | 37 | 52 | 34 |
| Range | 78-117 | 30-47 | 46-60 | 25-42 |

+Days after August 31

The mean plant height for the superior group in low- and high-stress nursery environments (90 cm and 49 cm, respectively) were similar to the middle group (92 cm and 53 cm, respectively, Table 11). Plant maturities within low- and high-stress nursery environments were similar for all three groups, but, as a group, the top 16 lines matured approximately 2-3 days earlier (Table 11).

Overall, it appears that selecting for the highest yielding lines would not have led to the lines which were either shorter and earlier or taller and later, etc., since the superior and non-superior lines did not follow any trend of this type.

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# PART 3: SUMMARY AND CONCLUSION

# CHAPTER 1

## SUMMARY AND CONCLUSION

The research was conducted over a duration of five years (1982-1986) at two locations [Plateau (Crossville) and Milan Experiment Stations in East and West Tennessee, respectively]. Each location provided a low-stress (optimum soil pH and fertility) and a high-stress (low soil pH and fertility) nursery environment which were maintained under these conditions throughout the duration of the study. In 1985 and 1986 five additional locations (Knoxville, Grand Junction, Springfield, Spring Hill, and Greeneville) were used as yield trial test sites for the purpose of obtaining more extensive information about yield and broader adaptability of the soybean lines. The plant material consisted of six soybean crosses with eight lines per cross (total of 48 lines) plus two check cultivars 'Essex' and 'Forrest'.

The soil at the Plateau low-stress site was classified as a Typic Hapludult and the high-stress site was classified as an Aquic Fragiudult and a Typic Hapludult. The soil at the Milan low-stress site was classified as an Aquic Udifluvent over a buried Typic Ochraqualf and the high-stress site was classified as a Typic Fragiudalf and a Glossic Fragiudalf that intergraded to an Aeric Glossudalf. Soil physical analyses revealed no physical barriers (plow-pan or fragipan) to soybean root penetration. Overall, the soil chemistry analyses revealed a high aluminum concentration and low-pH which reduced the availability of P, Ca, Mg, and K, causing yield

reduction and poor growth of soybean lines at both high-stress sites. The mean yields for Plateau and Milan high- vs. low-stress sites over 4 years were 0.50 vs 2.00 and 0.74 vs 2.71 Mg ha $^{-1}$, respectively.

Analyses of variance (ANOVA) were conducted for individual year-nursery environments, combined low- and combined high-stress nursery environments across four years (1982, 84, 85, and 86), and over all locations per year for the yield trials to determine the effects of year(s), location(s) and their interactions on yield of the soybean lines. ANOVA for individual year-nursery environments indicated that genotypes did respond differently under different environmental and cultural conditions. ANOVAs for combined types of nursery environments (LS or HS) gave further indications that the mean yields of the soybean lines were significantly (P  0.01) different when averaged over years and locations. Finally, ANOVA of yield trials also indicated significant (P  0.01) differences among soybean lines with respect to their yield capacity in a range of environments, indicating that it is possible to differentiate the "superior" lines from non-superior lines within a group.

Simulated selection was performed for the superior versus non-superior soybean lines on all nursery environment-location-year combinations. The top 16 superior lines were based on a 33% selection intensity which was later increased to 20% (top 10 lines) selection intensity for comparative purposes. The best lines (top 3) were the same within the 16 superior group as within the 10 superior group.

Simulated selection revealed that 32 to 56 percent (5-9 out of 16 lines) of the superior lines could have been selected based on mean

performance in either a low- or high-stress nursery environment with one year of testing. The effectiveness of selection was improved somewhat if the number of years and site combinations were increased but not enough to warrant the extra labor and expense for preliminary testing. Furthermore, at least one of the top 3 lines ranked in the top one-third in every case so the "best" line would have been saved regardless of the type of nursery environment-location-year combination used for testing. The comparison between 33 and 20% selection intensity for nursery site-location-year combinations revealed that increasing the selection intensity brought about a reduction in the percentage of the superior lines that would be selected in low- or high-stress environments. Also, the chances of obtaining at least one of the top 3 superior lines were generally lower for 20% compared to 33% selection intensity and in some cases the chance was zero for 20%. Based on these results a selection intensity greater than 33% is not advised at the preliminary yield testing stage.

Overall, the simulated selection results indicated that it is not necessary to establish and maintain yield test sites which have acid soils that are low in fertility for the purpose of selecting soybean lines that perform well relative to others under these conditions. This means that soybean breeders can conserve time, resources, and labor by selecting the superior lines in low-stress nursery environments and expect them to be the superior performers in high-stress environments, and vice versa.

The stability analyses of the individual soybean lines indicated that the 16 superior lines were the ones that generally had the

greatest yield response to changes in environmental conditions which influenced yield. Therefore, they were "stable" in the sense that they ranked in the top group regardless of the productivity level of the environment. Stability analyses among the six crosses provided evidence that 11 of the 16 superior lines came from two crosses and the best cross [Essex x (Bay x N73-520)] also contained the top 3 superior lines (TN82-264,TN82-265, and TN82-268).

Plant height and maturity were analyzed to determine if selecting for the highest yielding lines was an indirect result of a line being shorter and earlier or taller and later or some other combination. No such trend occurred because means and range of plant height and maturity for the superior lines were similar to those of the non-superior lines in low-stress as well as in high-stress environments. Finally, the top 3 lines represented a range in maturity and plant height which were similar to those of the three groups.

# APPENDIX

Table A-1. Plateau low-stress soil profile classification (Pit 1).

| Horizon | Depth | Description |
|---|---|---|
| Ap | 0-18 cm | brown (10YR 4/1) silt loam; weak medium granular structure; very friable; many medium, fine, and very fine roots; slightly acid; abrupt wavy boundary. |
| A/E | 18-28 cm | brown (10YR 4/3) silt loam with mixing of yellowish brown (10 yr 5/4) subsurface material; weak fine subangular blocky structure; very friable, many medium, fine, and very fine roots; slightly acid; clear wavy boundary. |
| BE | 28-41 cm | yellowish brown (10YR 5/4) silty clay loam; weakmedium and fine subangular blocky structure; friable; common fine and very fine roots; common fine iron and manganese concretions; moderately acid. |
| Bt1 | 41-41 cm | yellowish brown (10YR 5/6) silty clay loam; moderate medium and fine subangular blocky structure; friable; common fine and very fine; |
| Bt2 | 51-69 cm | yellowish brown (10YR 5/6) silty clay loam; moderate medium and fine subangular blocky structure; firm; few fine and very fine roots; grayish brown (10YR 5/2) and pale brown (10YR 6/3) clay films on faces of peds; very strongly acid. |
| Bt3 | 69-81 cm | brownish yellow (10YR 6/8) and light gray (10YR 6/1) silty clay loam; moderate medium subangular blocky structure, friable; few fine and very fine roots; pale brown (10YR 6/3) and yellowish brown (10YR 5/6) clay films on faces of peds; strongly acid; clear irregular boundary. |

Table A-1. (continued)

| Horizon | Depth | Description |
|---|---|---|
| C | 81-117 cm | light gray (10YR 7/1) and 10YR 6/1) and yellowish brown (10YR 6/8) loam; massive; friable; 15% coarse fragments, strongly acid; gradual irregular boundary. |
| CR | 117- cm | fine grained sandstone and siltstone with slight dip. |

Classification
fine silty, mixed mesic Typic Hapludult

Series
undefined

Table A-2. Plateau low-stress soil profile classification (Pit 2).

| Horizon | Depth | Description |
|---|---|---|
| Ap1 | 0-18 cm | yellowish brown (10YR 5/4) fine sandy loam; moderate medium granular structure; friable; many medium and fine roots; moderately acid; abrupt smooth boundary. |
| Ap2 | 18-25 cm | yellowish brown (10YR 5/4) fine sandy loam; weak medium subangular blocky structure; friable; common medium and fine roots; moderately acid; abrupt smooth boundary. |
| Bw | 25-33 cm | yellowish brown (5YR 5/4) fine sandy loam; weak medium subangular blocky structure; friable; few fine and very fine roots; strongly acid; clear wavy boundary. |
| E | 33-41 cm | pale brown (10YR 6/3) loam; weak coarse prismatic parting to moderate medium subangular blocky structure; friable; few fine and very fine roots; very strongly acid; clear wavy boundary. |
| Btx | 41-53 cm | pale brown (10YR 6/3) loam; yellowish brown (10YR 5/6) and strong brown (10YR 5/6) mottles; weak medium prismatic parting to moderate medium subangular blocky structure; 60% friable; 40% firm and brittle; very few very fine roots along prism faces; 10% slag gravel at base; very strongly acid; clear wavy boundary. |
| 2Bt | 53-81 cm | strong brown (7.5YR 5/6) and yellowish brown (10YR 5/4) clay loam; pale brown (10YR 6/3) mottles; moderate medium and fine subangular blocky structure; friable; brown (10YR 4/3) clay films on faces of peds, grayish brown (10YR 5/2) root channel linings; 15% coarse fragments; very strongly acid; abrupt irregular boundary. |
| 2C | 81-102 cm | light gray (10YR 7/1), yellowish brown (10YR 5/6), and strong brown (7.5YR 5/8) loam; massive; friable; 35% coarse fragments; very strongly acid, gradual irregular boundary. |

Table A-2. (continued)

| Horizon | Depth | Description |
|---|---|---|
| 2Cr | 102- cm | interbedded fine grained sandstone and siltstone.* |

Classification
coarse loamy, mixed, mesic Typic Hapludult+

Series
undefined

+Implies subgroup of Fragic Hapludult

*Bedrock occurs approximately 165 cm

Table A-3. Plateau high-stress soil profile classification (Pit 1).

| Horizon | Depth | Description |
|---|---|---|
| Ap | 0-15 cm | yellowish brown (10YR 5/4) fine sandy loam; weak fine granular structure; very friable; many coarse, medium, fine, and very fine roots; few grayish brown (10YR 5/2) organic coats, abrupt wavy boundary. |
| Bt1 | 15-33 cm | yellowish brown (10YR 5/4) loam; moderate coarse subangular blocky structure; friable; common fine and very fine roots; black (10YR 2/1) root channel lining; 1% coarse fragments. |
| Bt2 | 33053 cm | light olive brown (2.5YR 5/4) heavy silt loam; few distinct grayish brown (10YR 5/2) mottles; moderate medium subangular blocky structure; friable; few fine and very fine roots; black (10YR 2/1) root channel linigs; 1% coarse fragments. |
| 2Ex/ 2Btx1 | 53-81 cm | light olive brown (2.5YR 5/4) silt loam; common distinct brownish gray (2.6YR 6/2) mottles; moderate medium and fine subangular blocky structure; few very fine roots; very few (7.5YR 4/4) clay films on faces of peds; few strong brown (7.5YR 5/6) stains, light gray (10YR 7/1) silt coats on faces of peds; common medium iron and manganese concretions. |
| 2Btx2 | 81-117 cm | yellowish brown (10YR 5/4) silty clay loam with light gray (10YR 7/1) tongues of silt loam; moderate medium and fine subangular block structure; firm; brownish gray (10YR 5/2) clay films on faces of peds; few black (10YR 2/1) root channel linings; few patchy red (2.5YR 4/8) stains gradual wavy boundary. |

Table A-3. (continued)

| Horizon | Depth | Description |
|---|---|---|
| 2Bt1 | 117-140 cm | strong brown (7.5YR 5/6) and brownish yellow (10YR 6/6) silty clay loam; moderate medium subangular blocky structure; firm; gray (10YR 5/1) and pale brown (10YR 6/3) clay films on faces of peds; black (10YR 2/1) root channel linings; thin patchy red (2.5YR 4/8) stains. |

Classification
fine-loamy, silicious, mesic Aquic Fragiudult

Series
undefined

Table A-4. Plateau high-stress soil profile classification (Pit 2).

| Horizon | Depth | Description |
|---|---|---|
| Ap | 0-10 cm | dark brown (10YR 4/3) loam; weak fine granular structure; very friable; many coarse, medium, fine, and very fine roots, abrupt wavy boundary. |
| A | 10-18 cm | dark brown (10YR 4/3) loam with yellowish brown (10YR 5/4) subsoil mixing; weak medium and fine subangular blocky structure; very friable; many fine and very fine roots. |
| Bt1 | 18-43 cm | yellowish brown (10YR 5/4) loam; weak medium subangular blocky structure; friable; common fine and very fine roots; few black (10YR 2/1) root channel linings; clear wavy boundary. |
| Bt2 | 43-66 cm | light yellowish brown (10YR 6/4) loam; moderate medium and fine subangular blocky structure; friable; few fine and very fine roots; strong brown (7.5YR 5/8) stains; 5% coarse fragments; clear wavy boundary. |
| 2E/Bt | 66-84 cm | light yellowish brown (10YR 6/4) E part, and yellowish red (5YR 5/8) silty clay laom Bt part; moderate medium and fine subangular blocky structure; friable; few fine and very fine roots; yellowish red (5YR 5/8) and yellowish brown (10YR 5/4) clay films on faces of peds; dark grayish brown (10YR 4/2) root channel linings; clear wavy boundary. |
| 2Bt1 | 88-107 cm | light yellowish brown (10YR 6/4) silty clay loam; moderate medium and fine subangular blocky structure; friable; strong brown (7.5YR 5/6) clay films on faces of peds; yellowish red (5YR 5/8) stains; gradual wavy boundary. |

Table A-4. (continued)

| Horizon | Depth | Description |
|---|---|---|
| 2Bt2 | 107-122 cm | brownish yellow (10YR 6/6) and strong brown (10YR 5/6) silty clay loam; moderate medium subangular blocky structure; friable; light reddish brown (5YR 6/4) and reddish gray (5YR 5/2) clay films on faces of peds; red (2.5YR 4/8) iron stains; 15% siltstone and sandstone gravel fragments. |

Classification
fine-loamy, siliceous, mesic Typic Hapludult

Series
undefined

Table A-5. Milan low-stress soil profile classification (Pit 1).

| Horizon | Depth | Description |
|---|---|---|
| Ap massive; | 0-15 cm | yellowish brown (10YR 5/4) silt loam; very friable; common fine roots; slightly acid; abrupt smooth boundary. |
| C1 few | 15-20 cm | dark yellowish brown (10YR 4/4) silt loam; fine distinct light grey (10YR 7/2) and yellowish brown (10YR 5/6) mottles; massive; friable; common bedding planes; few fine roots; strongly acid; abrupt smooth boundary |
| C2 | 30-76 cm | yellowish brown (10YR 5/4) silt loam; common fine distinct light grey (2.5YR 7/2) and grayish brown (2.5YR 5/2) mottles; massive; friable; few thin bedding planes; strongly acid; smooth boundary. |
| Ab | 76-89 cm | brown (10YR 4/3) silt loam; common fine distinct greyish brown (10YR 5/2) mottles; massive; friable; common fine pores and voids; very strongly acid; clear wavy boundary. |
| Ab/ Btgb | 189-99 cm | brown (10YR 4/3) silt loam; few fine distinct yellowish brown (10YR 5/6) and common medium distinct light brownish grey (10YR 6/2) mottles; weak medium subangular blocky structure; friable; thick discontinuous clay films; few fine manganese concretions; very strongly acid; clear wavy boundary. |
| Btgb2 | 99-152 cm | light brownish grey (2.5YR 6/2) silty clay loam; common coarse distinct yellowish brown (10YR 5/4) few fine distinct white (10YR 8/1) and few fine prominent strong brown (7.5YR 5/8) mottles; moderate medium subangular blocky structure; friable; few manganese concretions; very strongly acid; clear wavy boundary. |

Table A-5. (continued)

| Horizon | Depth | Description |
|---|---|---|
| Btgb3 | 152-203 cm | light brownish grey (10YR 6/2) silt loam; few fine distinct yellowish brown (10YR 5/4 adn 5/8) mottles; weak medium subangular blocky structure; friable; few coarse and common medium and fine manganese concretions; very strongly acid. |

Classification

Aquic Udifluvent coarse-silty, mixed, acid, thermic (10YR 5/4) over a buried Typic Ochraqualf fine-silty, mixed, thermic coarse-silty, mixed, acid, thermic

Series

Collins silt loam 0-2% slopes

Table A-6. Milan low-stress soil profile classification (Pit 2).

| Horizon | Depth | Description |
|---|---|---|
| Ap | 0-18 cm | dark yellowish brown (10YR 4/4) fine sandy loam, weak medium granular structure; very friable; few fine manganese concretions; neutral; abrupt smooth boundary. |
| A/C | 18-23 cm | stratified brown (10YR 5/3) silt loam and strong brown (7.5YR 4/6) sandy loam; common fine distinct brownish yellow (10YR 6/6) mottles; weak fine platy structure; very friable; slightly acid; abrupt smooth boundary |
| C1 | 23-41 cm | yellowish brown (10YR 5/4) silt loam; common fine distinct yellowish brown (10YR 5/6), common medium distinct light brownish grey (10YR 6/2), and common coarse distinct strong brown (7.5YR 4/6) mottles; massive; friable; few fine manganese concretions and stains; strongly acid; clear smooth boundary |
| C2 | 41-79 cm | dark yellowish brown (10YR 4/4) silt loam; few fine distinct light brownish grey (10YR 6/2) and yellowish brown (10YR 5/6, 5/8) mottles; massive friable; few fine manganese concretions and stains; strongly acid; clear irregular boundary. |
| AB | 79-94 cm | greyish brown (10YR 5/2) silt loam; common coarse distinct light brownish grey (10YR 6/2) and few fine distinct yellowish brown (10YR 6/5) and light yellowish brown (10YR 6/4) mottles; weak medium subangular blocky structure; friable; few fine manganese concretions; common crayfish channels; very strongly acid. |

Table A-6. (continued)

| Horizon | Depth | Description |
|---|---|---|
| Btbg | 93-175 cm | light brownish grey (10YR 6/2) silty clay loam; common medium distinct brown (10YR 5/3) and few fine distinct yellowish brown (10YR 9/8) mottles; weak medium subangular blocky structure; friable; thin discontinuous clay skins on ped faces; common fine and medium manganese concretions; common crayfish channels; very strongly acid; gradual wavy boundary |
| Cb | 175-203 cm | light brownish grey (20YR 6/2) silt loam; common medium distinct brown (10YR 5/3) and few fine distinct yellowish brown (10YR 5/8) mottles; massive; friable; very strongly acid. |

Classification

Aquic Udifluvent, coarse-silty, mixed, acid, thermic over a buried Typic Ochraqualf, fine silty, mixed, thermic

Series

Collins silt loam 1-2% slopes

Table A-7. Milan high-stress soil profile classification (Pit 1).

| Horizon | Depth | Description |
|---|---|---|
| Ap | 0-13 cm | dark yellowish brown (10YR 4/4) silt loam; weak medium granular structure; very friable; strongly acid; clear smooth boundary. |
| Bt | 13-46 cm | yellowish brown (10YR 5/6) silt loam; common fine distinct brown (10YR 5/3) and light yellowish brown (10YR 6/4) mottles; weak medium subangular blocky structure; friable; thin discontinuous clay skins on ped faces; few fine roots; few manganese concretions and nodules 5 mm in diameter; strongly acid; gradual wavy boundary. |
| Bx/E | 46-56 cm | yellowish brown (10YR 5/4) (Bx) and light gray (10YR 7/2) (E) silt loam; common fine distinct very pale brown (10YR 7/3) and few fine distinct yellowish brown (10YR 5/6) mottles; weak medium prismatic and weak medium subangular blocky structure; firm and friable; common fine and medium manganese concretions; few fine roots; very strongly acid; clear irregular boundary. |
| Bx1 | 56-91 cm | mottled strong brown (7.5yr 4/6), ligh brownish grey (10YR 6/2) and yellowish brown (10YR 5/6) silt loam; moderate medium prismatic parting to moderate medium subangular blocky structure; frim and brittle; white (10YR 8/1) silt coatings following vertical seams; vertical seams 1-3 inches wide and 5-8 inches apart; common medium manganese concretions; very strongly acid; clear irregular boundary (mixed zone). |
| Bx2 | 91-137 cm | yellowish brown (10YR 5/4) silt loam; common fine distinct pale brown (10YR 6/3) and yellowish brown (10YR 5/8) mottles; moderate coarse prismatic parting to moderate medium subangular blocky structure; firm and brittle; white (10YR 8/1) following vertical seams; sand content approximately 10 percent; strongly acid; gradual wavy boundary. |

Table A-7. (continued)

| Horizon | Depth | Description |
|---|---|---|
| 2BC | 137-213 cm | yellowish brown (10YR 5/6) silt loam; common medium distinct pale brown (10YR 6/3) and strong brown (7.5Yr 5/8) and common coarse distinct yellowish brown (7.5YR 5/4) mottles; weak medium subangular blocky structure; friable; sand content approximately 15-20 percent increases with depth; strongly acid. |

Classification
Glossic Fragiudalf, fine silty, mixed, thermic

Series
Grenada silt loam 2-5% slopes, eroded

Table A-8. Milan high-stress soil profile classification (Pit 2).

| Horizon | Depth | Description |
|---|---|---|
| Ap | 0-20 cm | dark yellowish brown (10YR 4/4) silt loam; weak medium granular structure; very friable; common fine roots; thin discontinuous clay films; strongly acid; clear wavy boundary. |
| Bt | 20-43 cm | brownish yellow (10YR 6/6) silt loam; few fine distinct yellowish red (7.5YR 5/8) and common fine distinct light yellowish brown (10YR 6/4) mottles; weak medium subangular blocky structure; friable; thin discontinuous clay skins on ped faces; few fine roots and few coarse root channels; few fine manganese concretions; very strongly acid; gradual wavy boundary. |
| Bx/E | 43-66 cm | yellowish brown (10YR 5/4 (Bx) and light gray (10YR 7/2) (E) silt loam; common medium distinct light gray (10YR 7/2), yellowish red (7.5YR 5/8) and light yellowish brown (10YR 6/4) mottles; moderate medium prismatic and moderate medium subangular blocky strucutre; firm and friable; common fine and medium manganese concretions; few fine roots; very strongly acid; clear irregular boundary. |
| Bx | 66-117 cm | brown (10YR 5/3) silt loam; common medium distinct light brownish gray (2.5YR 6/2) and common fine prominent yellowish red (7.5YR 5/8) mottles; moderate medium prismatic parts to moderate medium subangular blocky structure; firm and brittle; white (10YR 8/1) silt matings in vertical seams; vertical seams 2.5-6 cm wide and 13-80 cm apart; very strongly acid; gradual wavy boundary. |
| 2Bt1 | 117-152 cm | yellowish brown (10YR 5/6) silt loam; common coarse distinct light yellowish brown (10YR 6/4), few fine prominent red (2.5YR 5/8), and common medium distinct light gray (10YR 7/2) mottles; weak medium subangular blocky structure; friable; sand content approximately 15-25% increasing with depth; strongly acid; gradual wavy boundary. |

Table A-8. (continued)

| Horizon | Depth | Description |
|---|---|---|
| 2Bt2 | 152-168 cm | light yellowish brown (10YR 6/4) silt loam; common coarse prominent strong brown (7.5YR 5/8 and 4/6) and common medium distinct light brownish gray (10YR 6/2) mottles; weak medium, subangular blocky structure; friable; seed content approximately 15-25% increasing with depth; common fine iron and manganese concretions; strongly acid; gradual wavy boundary. |
| 3BC | 168-198 cm | yellowish brown (10YR 5/8), light brownish gray (10YR 6/2), and yellowish brown (10YR 5/4) sandy clay loam; few fine distinct pinkish gray (7.5YR 6/2) mottles; weak medium subangular blocky structure; friable; strongly acid. |

Classification
fine silty mixed thermic Typic Fragiudalf

Series
Providence silt loam 2-5% slopes - eroded

Table A-9. Milan high-stress soil profile classification (Pit 3).

| Horizon | Depth | Description |
|---|---|---|
| Ap | 0-10 cm | dark yellow brown (10YR 4/4) silt loam; weak medium granular structure; very friable; few fine & medium manganese concretions; common fine roots; strongly acid; clear smooth boundary. |
| Bw1 | 10-25 cm | yellowish brown (10YR 5/6) silt loam; weak medium subangular block structure; friable; few fine manganese concretions; few fine and coarse roots; very strongly acid; clear smooth boundary. |
| Bw2 | 25-33 cm | yellowish brown (10YR 5/6) silt loam; common medium distinct light yellowish brown (10YR 6/4) and few fine distinct strong brown (7.5YR 5/8) mottles; moderate medium subangular blocky structure; friable; few fine manganese concretions; few fine roots; very strongly acid; clear smooth boundary. |
| E | 33-46 cm | light gray (10YR 7.1) silt loam; common coarse faint light gray (10YR 7/2) and few fine prominent strong brown (7.5YR 5/8) mottles; weak medium subangular blocky parting to weak medium granular structure; very friable; common fine and medium manganese concretions and nodules; very strongly acid; clear irregular boundary. |
| Bx1 | 46-140 cm | brown (10YR 5/3) silt loam; common coarse distinct light brownish gray (10YR 6/2), common medium distinct yellowish brown (10YR 5/8), and common fine distinct yellowish brown (10YR 4/6) mottles; moderate medium prismatic parting to moderate medium subangular blocky structure; firm and brittle; white (10YR 8/1) silt coatings following veritcal seam; vertical seams 5-13 cm wide and 10-15 cm apart; very strongly acid. |

Table A-9. (continued)

| Horizon | Depth | Description |
|---|---|---|
| 2Bx2 | 140-157 cm | mottled strong brown (7.5YR 5/8), light yellowish brown (10YR 6/4) and light brownish gray (10YR 6/2) loam; moderate medium prismatic parting to moderate medium subangular blocky structure; firm and brittle, light gray (10YR 7/2) silt coatings following vertical seams; strongly acid; gradual wavy boundary. |
| 2BC | 157-216 cm | brownish yellow (10YR 6/6) fine sandy loam; few fine faint brownish yellow (10YR 6/8)and few medium distinct pale brown (10YR 6/3) mottles; weak medium subangular block structure; friable; moderately acid. |

Classification
Glossic Fragiudalf intergrade to Aeric Glossudalf

Series
Grenada silt loam 2-5% slopes, severely eroded

Table A-10. Mean yield (Mg $ha^{-1}$) for soybean lines and pedigree at each nursery environment within each location and year.

| Line | Pedigree | Plateau | | Milan | | Plateau | | Milan | |
|---|---|---|---|---|---|---|---|---|---|
| | | LS+ | HS+ | LS | HS | LS | HS | LS | HS |
| | | 1982 | | | | 1983 | | | |
| TN82-230 | Essex | 2.12 | 1.23 | 3.07 | 0.72 | 2.19 | 0.56 | 1.44 | 0.31 |
| -231 | (Forrest | 1.95 | 1.26 | 2.00 | 0.94 | 2.25 | 0.41 | 1.62 | 0.24 |
| -232 | x OK963) | 1.96 | 1.30 | 3.14 | 0.52 | 2.24 | 0.45 | 2.33 | 0.21 |
| -233 | | 1.96 | 1.66 | 2.04 | 0.76 | 2.21 | 0.57 | 1.46 | 0.27 |
| -234 | | 1.94 | 1.16 | 2.53 | 0.91 | 2.17 | 0.43 | 1.80 | 0.27 |
| -235 | | 2.21 | 0.99 | 2.23 | 0.82 | 2.07 | 0.39 | 1.29 | 0.25 |
| -236 | | 2.46 | 1.08 | 2.74 | 0.70 | 2.24 | 0.52 | 1.68 | 0.26 |
| -237 | | 1.71 | 0.79 | 2.28 | 0.52 | 2.13 | 0.44 | 1.59 | 0.24 |
| | Mean | 2.00 | 1.18 | 2.50 | 0.74 | 2.18 | 0.47 | 1.65 | 0.26 |
| TN82-238 | Essex x | 2.63 | 1.31 | 2.07 | 0.82 | 2.15 | 0.35 | 1.27 | 0.31 |
| -239 | Hodgson | 1.82 | 1.19 | 3.34 | 0.60 | 2.33 | 0.46 | 1.27 | 0.26 |
| -240 | | 2.19 | 1.19 | 2.82 | 0.69 | 2.07 | 0.36 | 1.04 | 0.28 |
| -241 | | 2.34 | 2.99 | 2.84 | 0.70 | 2.28 | 0.34 | 2.05 | 0.39 |
| -242 | | 2.60 | 1.09 | 2.76 | 0.95 | 2.45 | 0.41 | 1.74 | 0.36 |
| -243 | | 2.02 | 1.40 | 2.86 | 0.63 | 2.40 | 0.34 | 2.11 | 0.30 |
| -244 | | 2.24 | 1.00 | 2.90 | 0.64 | 2.23 | 0.40 | 1.39 | 0.37 |
| -245 | | 1.89 | 1.24 | 2.70 | 1.02 | 2.15 | 0.38 | 1.62 | 0.30 |
| | Mean | 2.29 | 1.18 | 2.78 | 0.76 | 2.26 | 0.38 | 1.56 | 0.31 |
| TN82-246 | J74-45 x | 1.51 | 0.77 | 3.21 | 0.83 | 1.79 | 0.38 | 1.67 | 0.20 |
| -247 | Ts72- | 1.38 | 0.68 | 3.00 | 0.87 | 1.84 | 0.35 | 2.18 | 0.22 |
| -248 | 824 | 1.85 | 1.03 | 2.70 | 0.81 | 1.97 | 0.41 | 1.90 | 0.28 |
| -249 | | 2.02 | 1.42 | 2.65 | 0.85 | 1.76 | 0.33 | 1.37 | 0.30 |
| -250 | | 1.71 | 0.87 | 2.86 | 0.86 | 1.55 | 0.26 | 2.17 | 0.28 |
| -251 | | 1.98 | 1.11 | 2.61 | 0.80 | 1.97 | 0.34 | 1.39 | 0.26 |
| -252 | | 1.97 | 0.83 | 3.63 | 0.71 | 2.09 | 0.37 | 1.88 | 0.23 |
| -253 | | 1.85 | 1.03 | 2.83 | 0.57 | 1.98 | 0.31 | 1.62 | 0.24 |
| | Mean | 1.78 | 0.97 | 2.94 | 0.79 | 1.87 | 0.34 | 1.77 | 0.24 |
| TN82-254 | J74-40 x | 1.42 | 0.97 | 2.39 | 0.88 | 1.36 | 0.27 | 1.79 | 0.36 |
| -255 | Ts72- | 1.40 | 1.11 | 2.70 | 0.86 | 2.12 | 0.45 | 2.42 | 0.33 |
| -256 | 824 | 1.71 | 0.82 | 2.93 | 0.66 | 1.89 | 0.23 | 1.58 | |
| -257 | | 1.39 | 0.72 | 2.56 | 0.78 | 1.59 | 0.37 | 1.99 | 0.30 |
| -258 | | 2.40 | 1.22 | 3.27 | 1.00 | 1.89 | 0.48 | 2.55 | 0.29 |
| -259 | | 2.10 | 0.17 | 2.90 | 1.07 | 1.54 | 0.36 | 1.59 | 0.29 |
| -260 | | 1.75 | 0.87 | 2.42 | 0.81 | 1.46 | 0.44 | 1.26 | 0.33 |
| -261 | | 1.35 | 1.20 | 2.54 | 0.81 | 1.85 | 0.41 | 1.53 | 0.34 |
| | Mean | 1.72 | 0.95 | 2.72 | 0.86 | 1.71 | 0.38 | 1.84 | 0.32 |

Table A-10. (continued)

| Line | Pedigree | Plateau LS | Plateau HS | Milan LS | Milan HS | Plateau LS | Plateau HS | Milan LS | Milan HS |
|---|---|---|---|---|---|---|---|---|---|
| TN82-262 | Essex x | 2.20 | 1.81 | 3.44 | 0.77 | 1.98 | 0.49 | 1.75 | 0.29 |
| -263 | (Bay x | 1.99 | 0.78 | 2.12 | 1.03 | 1.93 | 0.58 | 1.76 | |
| -264 | N73-520) | 2.99 | 1.27 | 3.77 | 1.02 | 2.16 | 0.39 | 1.34 | 0.23 |
| -265 | | 2.80 | 1.14 | 3.16 | 0.85 | 2.17 | 0.54 | 1.93 | 0.28 |
| -266 | | 1.87 | 1.31 | 2.75 | 0.80 | 1.94 | 0.38 | 1.96 | 0.30 |
| -267 | | 2.06 | 1.59 | 3.23 | 0.80 | 1.71 | 0.28 | 1.82 | 0.31 |
| -268 | | 3.03 | 1.43 | 3.67 | 0.96 | 2.16 | 0.52 | 1.34 | 0.37 |
| -269 | | 2.62 | 1.92 | 3.37 | 1.06 | 2.18 | 0.28 | 1.51 | 0.31 |
| | Mean | 2.45 | 1.41 | 3.21 | 0.91 | 2.03 | 0.43 | 1.67 | 0.30 |
| TN82-270 | Centen- | 1.74 | 1.09 | 4.02 | 1.20 | 1.79 | 0.43 | 2.07 | 0.26 |
| -271 | nial x | 1.31 | 0.50 | 3.01 | 1.12 | 1.79 | 0.31 | 2.42 | 0.22 |
| -272 | J74-45 | 2.20 | 1.10 | 2.74 | 0.75 | 1.83 | 0.32 | 1.74 | 0.16 |
| -273 | | 1.33 | 1.25 | 3.67 | 0.97 | 1.85 | 0.49 | 2.21 | 0.24 |
| -274 | | 1.48 | 0.90 | 3.74 | 1.09 | 1.90 | 0.45 | 2.19 | 0.31 |
| -275 | | 1.98 | 1.17 | 3.75 | 0.90 | 1.88 | 0.45 | 2.17 | 0.27 |
| -276 | | 2.09 | 1.00 | 2.80 | 0.95 | 2.02 | 0.33 | 2.03 | 0.38 |
| -277 | | 1.54 | 0.71 | 3.60 | 1.07 | 1.62 | 0.30 | 1.99 | 0.25 |
| | Mean | 1.71 | 0.97 | 3.42 | 1.01 | 1.84 | 0.38 | 2.10 | 0.26 |
| Forrest | | 2.56 | 1.08 | 3.01 | 0.97 | 2.46 | 0.34 | 1.93 | 0.18 |
| Essex | | 2.13 | 0.92 | 2.92 | 0.76 | 2.09 | 0.31 | 1.58 | 0.26 |
| | $LSD_{0.05}$ | 0.57 | 0.46 | 0.73 | 0.33 | 0.28 | 0.15 | 0.68 | 0.10 |
| | CV(%) | 20.81 | 30.64 | 18.39 | 29.08 | 10.41 | 27.98 | 28.51 | 27.68 |

| | | 1984 | | | | 1985 | | | |
|---|---|---|---|---|---|---|---|---|---|
| 82-230 | Essex x | 1.84 | 0.40 | 2.83 | 0.72 | 1.81 | 0.22 | 1.86 | 0.78 |
| -231 | (Forrest | 1.29 | 0.43 | 2.59 | 0.79 | 1.93 | 0.22 | 2.59 | 0.80 |
| -232 | x OK963) | 1.84 | 0.43 | 2.59 | 0.89 | 1.85 | 0.29 | 1.89 | 0.73 |
| -233 | | 1.35 | 0.38 | 2.36 | 1.06 | 1.70 | 0.29 | 1.94 | 0.98 |
| -234 | | 1.91 | 0.22 | 2.90 | 0.76 | 1.48 | 0.32 | 2.08 | 0.63 |
| -235 | | 1.27 | 0.42 | 2.62 | 0.99 | 1.75 | 0.25 | 2.24 | 0.67 |
| -236 | | 1.97 | 0.41 | 2.84 | 0.68 | 1.95 | 0.24 | 2.66 | 0.77 |
| -237 | | 1.53 | 0.25 | 2.43 | 0.57 | 1.55 | 0.18 | 2.27 | 0.58 |
| | Mean | 1.69 | 0.37 | 2.62 | 0.81 | 1.75 | 0.25 | 2.19 | 0.74 |
| TN82-238 | Essex/ | 2.02 | 0.44 | 2.97 | 0.65 | 2.12 | 0.21 | 2.62 | 0.65 |
| -239 | Hodgson | 1.69 | 0.46 | 3.41 | 0.85 | 2.39 | 0.20 | 2.30 | 0.73 |
| -240 | | 2.19 | 0.35 | 3.04 | 0.70 | 1.88 | 0.15 | 1.78 | 0.82 |
| -241 | | 1.50 | 0.52 | 3.12 | 0.84 | 2.43 | 0.20 | 2.39 | 0.99 |
| -242 | | 1.96 | 0.40 | 2.50 | 0.94 | 2.05 | 0.29 | 2.36 | 0.83 |
| -243 | | 1.90 | 0.33 | 2.75 | 0.73 | 2.11 | 0.23 | 2.23 | 1.10 |
| -244 | | 1.97 | 0.52 | 2.14 | 0.87 | 2.35 | 0.26 | 1.71 | 0.94 |
| -245 | | 1.57 | 0.37 | 2.18 | 0.90 | 2.08 | 0.26 | 1.97 | 1.10 |
| | Mean | 1.85 | 0.43 | 2.76 | 0.81 | 2.18 | 0.23 | 2.17 | 0.90 |

Table A-10. (continued)

| Line | Pedigree | Plateau | | Milan | | Plateau | | Milan | |
|---|---|---|---|---|---|---|---|---|---|
| | | LS | HS | LS | HS | LS | HS | LS | HS |
| TN82-246 | J74-45/ | 1.75 | 0.44 | 2.64 | 0.76 | 1.27 | 0.19 | 2.20 | 0.86 |
| -247 | Ts72- | 0.94 | 0.45 | 2.14 | 0.83 | 1.25 | 0.22 | 2.31 | 0.81 |
| -248 | 824 | 1.40 | 0.50 | 2.92 | 0.71 | 1.44 | 0.32 | 2.00 | 0.78 |
| -249 | | 1.40 | 0.48 | 2.36 | 0.70 | 1.47 | 0.31 | 2.29 | 0.72 |
| -250 | | 1.08 | 0.37 | 2.73 | 0.91 | 1.29 | 0.27 | 2.18 | 0.72 |
| -251 | | 1.33 | 0.45 | 2.31 | 0.83 | 1.30 | 0.20 | 2.45 | 0.83 |
| -252 | | 1.50 | 0.39 | 2.74 | 0.97 | 1.34 | 0.13 | 2.88 | 0.16 |
| -253 | | 1.37 | 0.48 | 2.19 | 0.92 | 1.37 | 0.14 | 2.01 | 0.64 |
| | Mean | 1.29 | 0.44 | 2.57 | 0.83 | 1.34 | 0.22 | 2.29 | 0.82 |
| TN82-254 | J74-40/ | 1.19 | 0.40 | 2.60 | 0.61 | 0.93 | 0.23 | 1.62 | 0.53 |
| -255 | Ts72- | 1.51 | 0.43 | 2.93 | 0.71 | 0.71 | 0.21 | 1.66 | 0.42 |
| -256 | 824 | 1.33 | 0.43 | 2.86 | 0.58 | 0.59 | 0.14 | 2.35 | 0.47 |
| -257 | | 1.23 | 0.41 | 2.98 | 0.54 | 1.02 | 0.18 | 1.93 | 0.67 |
| -258 | | 2.29 | 0.46 | 3.59 | 0.86 | 1.61 | 0.19 | 1.94 | 0.75 |
| -259 | | 1.76 | 0.22 | 2.64 | 0.67 | 1.60 | 0.15 | 2.09 | 0.68 |
| -260 | | 0.33 | 0.28 | 2.99 | 0.61 | 1.27 | 0.21 | 1.62 | 0.51 |
| -261 | | 1.86 | 0.37 | 2.98 | 0.80 | 1.51 | 0.25 | 1.94 | 0.70 |
| | Mean | 1.50 | 0.37 | 2.95 | 0.67 | 1.40 | 0.19 | 1.89 | 0.59 |
| TN82-262 | Essex x | 1.50 | 0.39 | 2.77 | 0.61 | 1.80 | 0.25 | 2.25 | 0.60 |
| -263 | (Bay x | 1.66 | 0.34 | 2.86 | 0.57 | 1.62 | 0.23 | 2.18 | 0.71 |
| -264 | N73-520) | 1.96 | 0.41 | 2.92 | 0.83 | 1.66 | 0.22 | 2.25 | 0.68 |
| -265 | | 1.89 | 0.48 | 3.50 | 0.77 | 1.80 | 0.30 | 2.38 | 0.64 |
| -266 | | 1.67 | 0.49 | 3.07 | 0.95 | 1.42 | 0.25 | 2.38 | 0.72 |
| -267 | | 1.84 | 0.34 | 2.99 | 0.80 | 1.00 | 0.17 | 2.17 | 0.55 |
| -268 | | 1.66 | 0.24 | 2.04 | 0.98 | 1.95 | 0.23 | 1.73 | 0.65 |
| -269 | | 2.26 | 0.25 | 2.68 | 1.05 | 1.71 | 0.17 | 1.99 | 0.68 |
| | Mean | 1.81 | 0.38 | 2.85 | 0.82 | 1.62 | 0.23 | 2.17 | 0.65 |
| TN82-270 | Centen- | 1.25 | 0.29 | 2.90 | 0.78 | 1.23 | 0.20 | 2.34 | 1.00 |
| -271 | nial x | 1.26 | 0.39 | 3.08 | 0.87 | 0.82 | 0.19 | 1.83 | 0.64 |
| -272 | J74-45 | 1.47 | 0.34 | 2.63 | 0.76 | 1.26 | 0.19 | 2.02 | 0.80 |
| -273 | | 1.42 | 0.28 | 3.24 | 0.64 | 1.41 | 0.18 | 2.47 | 0.65 |
| -274 | | 1.67 | 0.25 | 3.77 | 0.76 | 1.33 | 0.21 | 2.50 | 0.91 |
| -275 | | 1.61 | 0.34 | 3.45 | 0.88 | 1.63 | 0.19 | 2.66 | 0.89 |
| -276 | | 1.67 | 0.30 | 3.51 | 0.87 | 1.34 | 0.16 | 2.12 | 0.73 |
| -277 | | 1.18 | 0.24 | 3.03 | 0.63 | 0.84 | 0.15 | 2.03 | 0.70 |
| | Mean | 1.44 | 0.31 | 3.20 | 0.77 | 1.23 | 0.18 | 2.24 | 0.79 |
| Forrest | | 1.47 | 0.60 | 2.88 | 0.74 | 1.50 | 0.16 | 2.92 | 0.65 |
| Essex | | 2.10 | 0.39 | 2.77 | 0.90 | 1.44 | 0.17 | 1.79 | 0.71 |
| | $LSD_{0.05}$ | 0.48 | 0.19 | 0.63 | 0.26 | 0.23 | 0.09 | 0.53 | 0.28 |
| | CV(%) | 22.13 | 36.83 | 16.57 | 24.59 | 10.93 | 34.12 | 18.01 | 27.75 |

Table A-10. (continued)

| Line | Pedigree | Plateau LS | Plateau HS | Milan LS | Milan HS | Plateau LS | Plateau HS | Milan LS | Milan HS |
|---|---|---|---|---|---|---|---|---|---|
| | | 1986 | | | | | | | |
| TN82-230 | Essex x | 3.05 | 0.24 | 2.93 | 0.48 | | | | |
| -231 | (Forrest | 2.70 | 0.26 | 2.89 | 0.54 | | | | |
| -232 | x OK963) | 2.56 | 0.30 | 2.89 | 0.51 | | | | |
| -233 | | 2.87 | 0.25 | 2.51 | 0.43 | | | | |
| -234 | | 2.76 | 0.37 | 2.45 | 0.49 | | | | |
| -235 | | 3.31 | 0.37 | 2.57 | 0.56 | | | | |
| -236 | | 2.59 | 0.37 | 3.89 | 0.60 | | | | |
| -237 | | 2.92 | 0.36 | 3.48 | 0.63 | | | | |
| | Mean | 2.85 | 0.31 | 2.85 | 0.53 | | | | |
| TN82-238 | Essex x | 2.37 | 0.44 | 3.06 | 0.54 | | | | |
| -239 | Hodgson | 2.63 | 0.32 | 3.27 | 0.62 | | | | |
| -240 | | 3.02 | 0.32 | 2.76 | 0.52 | | | | |
| -241 | | 2.05 | 0.24 | 2.55 | 0.50 | | | | |
| -242 | | 1.96 | 0.27 | 2.50 | 0.51 | | | | |
| -243 | | 2.56 | 0.36 | 3.35 | 0.53 | | | | |
| -244 | | 2.13 | 0.29 | 2.63 | 0.72 | | | | |
| -245 | | 2.43 | 0.35 | 2.71 | 0.58 | | | | |
| | Mean | 2.40 | 0.32 | 2.85 | 0.56 | | | | |
| TN82-246 | J74-45 x | 2.19 | 0.50 | 2.46 | 0.63 | | | | |
| -247 | Ts72-824 | 2.39 | 0.33 | 2.47 | 0.60 | | | | |
| -248 | | 2.49 | 0.30 | 2.12 | 0.61 | | | | |
| -249 | | 2.65 | 0.21 | 2.16 | 0.60 | | | | |
| -250 | | 2.22 | 0.30 | 2.31 | 0.41 | | | | |
| -251 | | 2.40 | 0.13 | 2.63 | 0.55 | | | | |
| -252 | | 1.96 | 0.22 | 3.27 | 0.61 | | | | |
| -253 | | 2.81 | 0.22 | 2.94 | 0.55 | | | | |
| | Mean | 2.39 | 0.28 | 2.54 | 0.57 | | | | |
| TN82-254 | J74-40 x | 3.25 | 0.33 | 3.03 | 0.53 | | | | |
| -255 | Ts72-824 | 3.30 | 0.31 | 2.86 | 0.76 | | | | |
| -256 | | 2.50 | 0.24 | 2.67 | 0.46 | | | | |
| -257 | | 2.85 | 0.28 | 3.26 | 0.56 | | | | |
| -258 | | 2.98 | 0.24 | 3.19 | 0.63 | | | | |
| -259 | | 2.53 | 0.32 | 2.50 | 0.40 | | | | |
| -260 | | 2.92 | 0.22 | 2.92 | 0.43 | | | | |
| -261 | | 3.38 | 0.22 | 2.82 | 0.69 | | | | |
| | Mean | 2.96 | 0.27 | 2.91 | 0.56 | | | | |

Table A-10. (continued)

| Line | Pedigree | Plateau LS | Plateau HS | Milan LS | Milan HS | Plateau LS | Plateau HS | Milan LS | Milan HS |
|---|---|---|---|---|---|---|---|---|---|
| TN82-262 | Essex x | 2.78 | 0.28 | 3.20 | 0.72 | | | | |
| -263 | (Bay x | 2.77 | 0.25 | 3.46 | 0.70 | | | | |
| -264 | N73-520) | 2.61 | 0.34 | 3.19 | 0.60 | | | | |
| -265 | | 2.87 | 0.28 | 3.61 | 0.54 | | | | |
| -266 | | 2.24 | 0.28 | 2.69 | 0.74 | | | | |
| -267 | | 2.05 | 0.20 | 2.77 | 0.57 | | | | |
| -268 | | 2.20 | 0.27 | 3.50 | 0.67 | | | | |
| -269 | | 1.95 | 0.20 | 2.74 | 0.54 | | | | |
| | Mean | 2.43 | 0.26 | 3.15 | 0.64 | | | | |
| TN82-270 | Centen- | 2.68 | 0.25 | 3.20 | 0.73 | | | | |
| -271 | nial x | 1.96 | 0.27 | 3.22 | 0.57 | | | | |
| -272 | J74-45 | 2.05 | 0.23 | 3.28 | 0.47 | | | | |
| -273 | | 2.27 | 0.34 | 3.36 | 0.71 | | | | |
| -274 | | 2.62 | 0.30 | 3.54 | 0.69 | | | | |
| -275 | | 2.41 | 0.23 | 3.29 | 0.98 | | | | |
| -276 | | 2.32 | 0.20 | 3.09 | 0.62 | | | | |
| -277 | | 2.34 | 0.32 | 3.20 | 0.70 | | | | |
| | Mean | 2.33 | 0.27 | 3.27 | 0.68 | | | | |
| Forrest | | 2.51 | 0.28 | 4.09 | 0.48 | | | | |
| Essex | | 2.29 | 0.28 | 2.99 | 0.67 | | | | |
| | $LSD_{0.05}$ | 0.38 | 0.15 | 0.70 | 0.21 | | | | |
| | CV(%) | 11.09 | 37.91 | 17.39 | 26.15 | | | | |

[+]LS= Low-Stress Nursery sites; HS= High-Stress Nursery sites.

Table A-11. Mean yield (Mg $ha^{-1}$) for soybean lines and pedigree at each yield trial location and year.

| Line | Pedigree | KLS+ | GLS+ | ALS+ | MTLS+ | HRLS+ | Mean |
|---|---|---|---|---|---|---|---|
| | | | | 1985 | | | |
| TN82-230 | Essex x | 1.38 | 2.21 | 2.45 | 1.67 | 1.94 | 1.93 |
| -231 | (Forrest | 2.01 | 2.26 | 2.38 | 2.13 | 2.30 | 2.22 |
| -232 | x OK963) | 1.80 | 2.43 | 2.45 | 1.59 | 2.31 | 2.12 |
| -233 | | 1.75 | 2.69 | 2.47 | 2.02 | 1.83 | 2.15 |
| -234 | | 1.53 | 2.53 | 2.32 | 2.11 | 1.84 | 2.07 |
| -235 | | 1.86 | 1.91 | 2.28 | 1.35 | 1.72 | 1.82 |
| -236 | | 1.94 | 1.91 | 2.77 | 1.83 | 2.04 | 2.10 |
| -237 | | 1.60 | 1.99 | 2.17 | 1.59 | 1.76 | 1.82 |
| | Mean | 1.69 | 2.24 | 2.41 | 1.79 | 1.97 | 2.03 |
| TN82-238 | Essex x | 1.51 | 1.88 | 2.47 | 1.97 | 2.07 | 1.98 |
| -239 | Hodgson | 1.39 | 2.24 | 2.92 | 2.06 | 2.29 | 2.18 |
| -240 | | 1.79 | 1.99 | 2.51 | 1.88 | 2.17 | 2.07 |
| -241 | | 1.58 | 1.94 | 2.68 | 1.75 | 1.97 | 1.98 |
| -242 | | 1.72 | 2.27 | 2.64 | 2.13 | 2.38 | 2.22 |
| -243 | | 1.66 | 1.82 | 2.67 | 1.84 | 2.28 | 2.05 |
| -244 | | 1.72 | 3.16 | 2.34 | 1.84 | 3.09 | 2.43 |
| -245 | | 1.75 | 1.97 | 2.72 | 1.83 | 1.80 | 2.01 |
| | Mean | 1.64 | 2.16 | 2.62 | 1.91 | 2.26 | 2.12 |
| TN82-246 | J74-45 x | 1.74 | 2.26 | 2.44 | 1.97 | 2.04 | 2.09 |
| -247 | Ts72-824 | 1.42 | 2.04 | 2.91 | 2.18 | 1.88 | 2.09 |
| -248 | | 1.50 | 2.19 | 2.79 | 1.79 | 1.93 | 2.04 |
| -249 | | 1.33 | 1.80 | 2.66 | 1.83 | 1.92 | 1.91 |
| -250 | | 1.42 | 1.79 | 2.20 | 1.41 | 1.74 | 1.71 |
| -251 | | 1.62 | 2.15 | 3.17 | 1.99 | 2.02 | 2.19 |
| -252 | | 1.77 | 2.00 | 3.07 | 2.12 | 2.01 | 2.19 |
| -253 | | 1.53 | 2.85 | 2.36 | 1.65 | 1.88 | 2.05 |
| | Mean | 1.54 | 2.13 | 2.70 | 1.87 | 1.93 | 2.03 |
| TN82-254 | J74-40 x | 1.44 | 1.25 | 2.32 | 1.41 | 1.29 | 1.54 |
| -255 | Ts72-824 | 1.73 | 2.30 | 2.57 | 1.44 | 1.69 | 1.95 |
| -256 | | 1.21 | 2.07 | 2.42 | 1.77 | 1.76 | 1.85 |
| -257 | | 1.54 | 1.45 | 2.59 | 1.67 | 1.28 | 1.71 |
| -258 | | 1.72 | 2.73 | 2.19 | 1.81 | 2.07 | 2.10 |
| -259 | | 1.49 | 2.07 | 2.47 | 1.69 | 1.98 | 1.94 |
| -260 | | 1.47 | 1.33 | 2.10 | 1.35 | 1.80 | 1.61 |
| -261 | | 2.05 | 2.12 | 2.09 | 2.29 | 1.89 | 2.09 |
| | Mean | 1.58 | 1.92 | 2.34 | 1.68 | 1.72 | 1.85 |

Table A-11. (continued)

| Line | Pedigree | KLS | GLS | ALS | MTLS | HRLS | Mean |
|---|---|---|---|---|---|---|---|
| TN82-262 | Essex x | 1.64 | 2.11 | 2.62 | 2.01 | 2.40 | 2.16 |
| -263 | (Bay x | 1.50 | 2.30 | 2.74 | 2.03 | 1.73 | 2.06 |
| -264 | N73-520) | 1.48 | 3.05 | 2.69 | 1.74 | 2.55 | 2.30 |
| -265 | | 1.62 | 2.57 | 2.67 | 1.89 | 1.56 | 2.06 |
| -266 | | 1.47 | 1.99 | 2.53 | 1.98 | 1.80 | 1.95 |
| -267 | | 1.73 | 2.77 | 2.78 | 1.76 | 1.75 | 2.16 |
| -268 | | 1.29 | 3.20 | 3.31 | 2.34 | 2.32 | 2.49 |
| -269 | | 1.24 | 2.92 | 3.07 | 1.70 | 1.83 | 2.15 |
| | Mean | 1.50 | 2.61 | 2.80 | 1.93 | 1.99 | 2.17 |
| TN82-270 | Centen- | 1.60 | 2.17 | 1.73 | 1.69 | 1.38 | 1.71 |
| -271 | nial x | 1.47 | 1.42 | 1.95 | 1.75 | 1.60 | 1.64 |
| -272 | J74-45 | 1.95 | 2.31 | 2.64 | 2.00 | 2.07 | 2.19 |
| -273 | | 1.70 | 2.52 | 2.30 | 1.76 | 1.61 | 1.98 |
| -274 | | 1.39 | 1.32 | 2.35 | 1.85 | 1.41 | 1.66 |
| -275 | | 1.78 | 1.69 | 2.78 | 1.87 | 1.41 | 1.91 |
| -276 | | 1.63 | 1.68 | 2.49 | 1.89 | 1.74 | 1.87 |
| -277 | | 1.27 | 1.44 | 2.45 | 1.67 | 1.18 | 1.60 |
| | Mean | 1.60 | 1.82 | 2.34 | 1.81 | 1.55 | 1.82 |
| | Forrest | 1.46 | 2.42 | 2.61 | 2.20 | 2.18 | 2.17 |
| | Essex | 1.87 | 2.69 | 2.45 | 1.61 | 1.94 | 2.11 |
| | $LSD_{0.05}$ | 0.32 | 0.52 | 0.67 | 0.53 | 0.36 | |
| | CV(%) | 14.95 | 17.85 | 19.45 | 21.24 | 13.87 | |
| | | | | 1986 | | | |
| Essex x | | 3.83 | 3.54 | 1.32 | 2.12 | 2.26 | 2.61 |
| -231 | (Forrest | 3.53 | 2.71 | 1.54 | 1.78 | 1.62 | 2.24 |
| -232 | OK963) | 3.92 | 2.81 | 1.35 | 1.98 | 1.57 | 2.33 |
| -233 | | 3.73 | 2.85 | 2.31 | | 1.56 | 2.36 |
| -234 | | 3.59 | 3.14 | 1.42 | 1.85 | 2.04 | 2.41 |
| -235 | | 3.64 | 2.52 | 1.54 | 2.25 | 1.98 | 2.39 |
| -236 | | 3.70 | 2.75 | 1.58 | 2.07 | 2.01 | 2.42 |
| -237 | | 3.08 | 2.73 | 1.13 | 1.80 | 1.95 | 2.14 |
| | Mean | 3.63 | 2.88 | 1.40 | 1.98 | 1.87 | 2.36 |
| TN82-238 | Essex x | 3.61 | 2.92 | 1.48 | 1.62 | 2.38 | 2.31 |
| -239 | Hodgson | 3.30 | 3.07 | 1.60 | 2.28 | 1.86 | 2.42 |
| -240 | | 3.26 | 2.52 | 1.67 | 1.88 | 2.12 | 2.29 |
| -241 | | 3.84 | 3.10 | 1.39 | 1.64 | 1.60 | 2.31 |
| -242 | | 3.43 | 2.79 | 1.53 | | 1.68 | 2.36 |
| -243 | | 3.53 | 2.70 | 1.64 | 2.17 | 1.82 | 2.37 |
| -244 | | 3.44 | 2.97 | 1.49 | 2.02 | 1.72 | 2.33 |
| -245 | | 3.94 | 2.50 | 1.63 | 1.91 | 1.96 | 2.39 |
| | Mean | 3.54 | 2.82 | 1.55 | 1.93 | 1.89 | 2.35 |

Table A-11. (continued)

| Line | Pedigree | KLS | GLS | ALS | MTLS | HRLS | Mean |
|---|---|---|---|---|---|---|---|
| TN82-246 | J74-45 x | 2.89 | 2.42 | 1.24 | 1.68 | 1.39 | 1.92 |
| -247 | Ts72-824 | 3.30 | 2.83 | 1.19 | 1.87 | 1.61 | 2.16 |
| -248 | | 3.66 | 2.55 | 1.48 | 1.87 | 1.75 | 2.26 |
| -249 | | 3.42 | 2.47 | 1.49 | 1.85 | 1.35 | 2.12 |
| -250 | | 3.12 | 2.62 | 1.19 | 1.96 | 1.70 | 2.12 |
| -251 | | 3.30 | 2.73 | 1.25 | 1.54 | 1.41 | 2.05 |
| -252 | | 3.11 | 2.72 | 1.66 | 1.91 | 1.69 | 2.22 |
| -253 | | 3.58 | 2.80 | 1.75 | 2.37 | 1.52 | 2.40 |
| | Mean | 3.30 | 2.64 | 1.41 | 1.88 | 1.55 | 2.16 |
| TN82-254 | J74-40 x | 3.35 | 2.42 | 1.36 | 2.29 | 2.23 | 2.33 |
| -255 | Ts72-824 | 3.80 | 2.73 | 1.61 | 2.16 | 2.25 | 2.51 |
| -256 | | 3.42 | 2.64 | 1.27 | 1.69 | 1.65 | 2.13 |
| -257 | | 3.34 | 2.43 | 1.30 | 2.51 | 2.09 | 2.33 |
| -258 | | 3.23 | 2.77 | 1.83 | 2.31 | 2.39 | 2.51 |
| -259 | | 3.43 | 2.34 | 1.02 | 1.94 | 1.69 | 2.08 |
| -260 | | 3.07 | 2.39 | 1.44 | 1.71 | 1.68 | 2.06 |
| -261 | | 3.15 | 2.64 | 1.84 | 2.67 | 2.26 | 2.51 |
| | Mean | 3.35 | 2.54 | 1.46 | 2.16 | 2.03 | 2.31 |
| TN82-262 | Essex x | 3.74 | 2.86 | 1.88 | 2.33 | 2.54 | 2.67 |
| -263 | (Bay x | 3.65 | 3.03 | 1.56 | 2.43 | 2.10 | 2.54 |
| -264 | N73-520) | 3.97 | 3.39 | 1.62 | 2.19 | 2.31 | 2.70 |
| -265 | | 4.28 | 3.20 | 2.35 | 2.60 | 2.30 | 2.95 |
| -266 | | 3.79 | 2.81 | 1.57 | 2.02 | 2.21 | 2.48 |
| -267 | | 3.75 | 3.23 | 1.57 | 2.36 | 2.90 | 2.76 |
| -268 | | 3.53 | 3.63 | 1.61 | 1.88 | 1.98 | 2.53 |
| -269 | | 3.22 | 3.22 | 1.92 | 2.00 | 2.20 | 2.51 |
| | Mean | 3.74 | 3.17 | 1.76 | 2.23 | 2.32 | 2.64 |
| TN82-270 | Centen- | 3.40 | 1.98 | 1.58 | 2.23 | 2.38 | 2.31 |
| -271 | nial x | 3.47 | 2.49 | 1.46 | 2.11 | 1.70 | 2.25 |
| -272 | J74-45 | 3.73 | 2.81 | 1.51 | 1.79 | 1.86 | 2.34 |
| -273 | | 3.63 | 2.48 | 1.56 | 2.59 | 1.82 | 2.42 |
| -274 | | 3.46 | 2.02 | 1.64 | 2.52 | 2.48 | 2.42 |
| -275 | | 3.86 | 2.30 | 1.65 | 2.80 | 2.31 | 2.58 |
| -276 | | 3.90 | 2.69 | 1.57 | 2.61 | 2.42 | 2.64 |
| -277 | | 3.49 | 2.47 | 1.60 | 2.07 | 1.77 | 2.28 |
| | Mean | 3.62 | 2.41 | 1.57 | 2.34 | 2.09 | 2.41 |
| Forrest | | 3.52 | 3.31 | 1.72 | 2.13 | 2.40 | 2.62 |
| Essex | | 3.38 | 3.12 | 1.65 | 1.93 | 1.53 | 2.32 |
| | $LSD_{0.05}$ | 0.58 | 0.52 | 0.37 | 0.44 | 0.59 | |
| | CV(%) | 12.22 | 17.85 | 7.63 | 15.49 | 22.20 | |

Table A-11. (continued)

| Line | Pedigree | KLS | GLS | ALS | MTLS | HRLS | Mean |
|---|---|---|---|---|---|---|---|
| | | 1985 + 1986 | | | | | |
| | | 2 yr. Mean | | | | | |
| TN82-230 | Essex x | 2.27 | | | | | |
| -231 | (Forrest | 2.23 | | | | | |
| -232 | x OK963) | 2.23 | | | | | |
| -233 | | 2.26 | | | | | |
| -234 | | 2.24 | | | | | |
| -235 | | 2.11 | | | | | |
| -236 | | 2.26 | | | | | |
| -237 | | 1.98 | | | | | |
| | Mean | 2.20 | | | | | |
| TN82-238 | Essex x | 2.15 | | | | | |
| -239 | Hodgson | 2.30 | | | | | |
| -240 | | 2.18 | | | | | |
| -241 | | 2.15 | | | | | |
| -242 | | 2.29 | | | | | |
| -243 | | 2.21 | | | | | |
| -244 | | 2.38 | | | | | |
| -245 | | 2.20 | | | | | |
| | Mean | 2.23 | | | | | |
| TN82-246 | J74-45 x | 2.01 | | | | | |
| -247 | Ts72-824 | 2.13 | | | | | |
| -248 | | 2.15 | | | | | |
| -249 | | 2.21 | | | | | |
| -250 | | 1.92 | | | | | |
| -251 | | 2.12 | | | | | |
| -252 | | 2.21 | | | | | |
| -253 | | 2.23 | | | | | |
| | Mean | 2.12 | | | | | |
| TN82-254 | J74-40 x | 1.94 | | | | | |
| -255 | Ts72-824 | 2.23 | | | | | |
| -256 | | 1.99 | | | | | |
| -257 | | 2.02 | | | | | |
| -258 | | 2.31 | | | | | |
| -259 | | 2.01 | | | | | |
| -260 | | 1.84 | | | | | |
| -261 | | 2.30 | | | | | |
| | Mean | 2.08 | | | | | |

Table A-11. (continued)

| Line | Pedigree | KLS | GLS | ALS | MTLS | HRLS | Mean |
|---|---|---|---|---|---|---|---|
| TN82-262 | Essex x | 2.42 | | | | | |
| -263 | (Bay x | 2.30 | | | | | |
| -264 | N73-520) | 2.50 | | | | | |
| -265 | | 2.51 | | | | | |
| -266 | | 2.22 | | | | | |
| -267 | | 2.46 | | | | | |
| -268 | | 2.51 | | | | | |
| -269 | | 2.33 | | | | | |
| | Mean | 2.41 | | | | | |
| TN82-270 | Centen- | 2.01 | | | | | |
| -271 | nial x | 1.95 | | | | | |
| -272 | J74-45 | 2.27 | | | | | |
| -273 | | 2.20 | | | | | |
| -274 | | 2.04 | | | | | |
| -275 | | 2.25 | | | | | |
| -276 | | 2.26 | | | | | |
| -277 | | 1.94 | | | | | |
| | Mean | 1.86 | | | | | |
| Forrest | | 2.40 | | | | | |
| Essex | | 2.22 | | | | | |
| | | ——— | | | | | |
| | $LSD_{0.05}$ | ——— | | | | | |
| | CV(%) | | | | | | |

+KLS, GLS, ALS, MTLS, and HRLS are defined in the Materials and Methods section of Chapter 2.

Table A-12. Soil test results of the five locations where the yield trials were grown in 1985 and 1986.

| Soil Parameter | Locations And Soil Fertility Levels | | | | |
|---|---|---|---|---|---|
| | Knoxville | Greeneville | Springfield | Spring Hill | Grand Junction |
| pH | 6.6 | 6.7 | 6.7 | 6.5 | 6.8 |
| P | High | High | High | High | High |
| K | High | High | High | High | High |

Table A-13. Mean yield and stability parameters for the superior (top group) and non-superior (middle and bottom group) soybean lines for combined high- and low-stress environments over four years and yield trials over two years.

| Line/Group | Pedigree | N | Yield | Reg. Coeff. | Std. Err. | Dev. from Reg. |
|---|---|---|---|---|---|---|
| | | | ------Mg ha$^{-1}$----- | | | |
| Top Group (Superior) | | | | | | |
| TN82-273 | Centennial x J74-45 | 26 | 1.78 | 1.07 | ± 0.07 | 0.09 |
| TN82-275 | Centennial x J74-45 | 26 | 1.88 | 1.09 | ± 0.07 | 0.11 |
| TN82-262 | Essex x (Bay x N73-520) | 26 | 1.91 | 1.07 | ± 0.05 | 0.05 |
| TN82-264 | Essex x (Bay x N73-520) | 26 | 1.99 | 1.16 | ± 0.06 | 0.08 |
| TN82-265 | Essex x (Bay x N73-520) | 26 | 2.00 | 1.20 | ± 0.05 | 0.06 |
| TN82-267 | Essex x (Bay x N73-520) | 26 | 1.84 | 1.08 | ± 0.07 | 0.10 |
| TN82-268 | Essex x (Bay x N73-520) | 26 | 1.94 | 1.10 | ± 0.10 | 0.21 |
| TN82-269 | Essex x (Bay x N73-520) | 26 | 1.87 | 0.99 | ± 0.08 | 0.14 |
| TN82-238 | Essex x Hodgson | 26 | 1.80 | 0.96 | ± 0.07 | 0.10 |
| TN82-239 | Essex x Hodgson | 26 | 1.88 | 1.08 | ± 0.05 | 0.06 |
| TN82-242 | Essex x Hodgson | 25 | 1.78 | 0.91 | ± 0.06 | 0.07 |
| TN82-243 | Essex x Hodgson | 26 | 1.82 | 0.99 | ± 0.04 | 0.04 |
| TN82-244 | Essex x Hodgson | 26 | 1.82 | 0.92 | ± 0.09 | 0.18 |
| TN82-258 | J74-40 x Ts72-824 | 26 | 1.91 | 1.05 | ± 0.06 | 0.08 |
| TN82-261 | J74-40 x Ts72-824 | 26 | 1.78 | 0.95 | ± 0.07 | 0.11 |
| TN82-252 | J74-45 x Ts72-824 | 26 | 1.78 | 1.01 | ± 0.07 | 0.11 |
| Middle Group (Non-Superior) | | | | | | |
| TN82-270 | Centennial x J74-45 | 26 | 1.73 | 0.99 | ± 0.08 | 0.15 |
| TN82-272 | Centennial x J74-45 | 26 | 1.73 | 1.02 | ± 0.04 | 0.04 |
| TN82-274 | Centennial x J74-45 | 26 | 1.78 | 1.07 | + 0.09 | 0.19 |
| TN82-276 | Centennial x J74-45 | 26 | 1.79 | 1.07 | ± 0.05 | 0.06 |
| TN82-263 | Essex x (Bay x N73-520) | 26 | 1.79 | 1.06 | ± 0.05 | 0.05 |
| TN82-266 | Essex x (Bay x N73-520) | 26 | 1.76 | 0.97 | ± 0.04 | 0.03 |
| TN82-230 | Essex x (Forrest x OK963) | 26 | 1.81 | 1.10 | ± 0.05 | 0.05 |
| TN82-231 | Essex x (Forrest x OK963) | 26 | 1.75 | 0.92 | ± 0.06 | 0.07 |
| TN82-232 | Essex x (Forrest x OK963) | 26 | 1.77 | 1.02 | ± 0.05 | 0.05 |
| TN82-233 | Essex x (Forrest x OK963) | 25 | 1.71 | 0.90 | ± 0.07 | 0.10 |
| TN82-234 | Essex x (Forrest x OK963) | 26 | 1.74 | 0.09 | ± 0.05 | 0.05 |
| TN82-236 | Essex x (Forrest x OK963) | 26 | 1.83 | 1.03 | ± 0.04 | 0.03 |
| TN82-240 | Essex x Hodgson | 26 | 1.78 | 0.97 | ± 0.05 | 0.05 |
| TN82-241 | Essex x Hodgson | 26 | 1.77 | 1.01 | ± 0.07 | 0.11 |
| TN82-245 | Essex x Hodgson | 26 | 1.75 | 0.90 | ± 0.05 | 0.05 |
| TN82-255 | J74-40 x Ts72-824 | 26 | 1.74 | 1.03 | ± 0.06 | 0.08 |

Table A-13. (continued)

| Line/Group | Pedigree | N | Yield | Reg. Coeff. | Std. Err. | Dev. from Reg. |
|---|---|---|---|---|---|---|
| Bottom Group (Non-Superior) | | | | | | |
| TN82-271 | Centennial x J74-45 | 26 | 1.56 | 0.96 | ± 0.07 | 0.10 |
| TN82-277 | Centennial x J74-45 | 26 | 1.60 | 1.03 | ± 0.07 | 0.11 |
| TN82-235 | Essex x (Forrest x OK963) | 26 | 1.71 | 0.93 | ± 0.06 | 0.08 |
| TN82-237 | Essex x (Forrest x OK963) | 26 | 1.60 | 0.96 | ± 0.06 | 0.07 |
| TN82-254 | J74-40 x Ts72-824 | 26 | 1.55 | 0.94 | ± 0.07 | 0.12 |
| TN82-256 | J74-40 x Ts72-824 | 26 | 1.60 | 1.01 | ± 0.03 | 0.02 |
| TN82-257 | J74-40 x Ts72-824 | 26 | 1.60 | 1.01 | ± 0.07 | 0.09 |
| TN82-259 | J74-40 x Ts72-824 | 26 | 1.64 | 0.97 | ± 0.05 | 0.04 |
| TN82-260 | J74-40 x Ts72-824 | 26 | 1.50 | 0.94 | ± 0.06 | 0.07 |
| TN82-246 | J74-45 x Ts72-824 | 26 | 1.63 | 0.87 | ± 0.05 | 0.06 |
| TN82-247 | J74-45 x Ts72-824 | 26 | 1.61 | 0.93 | ± 0.06 | 0.08 |
| TN82-248 | J74-45 x Ts72-824 | 26 | 1.67 | 0.93 | ± 0.04 | 0.04 |
| TN82-249 | J74-45 x Ts72-824 | 26 | 1.62 | 0.88 | ± 0.05 | 0.06 |
| TN82-250 | J74-45 x Ts72-824 | 26 | 1.55 | 0.89 | ± 0.04 | 0.03 |
| TN82-251 | J74-45 x Ts72-824 | 26 | 1.68 | 0.96 | ± 0.06 | 0.06 |
| TN82-253 | J74-45 x Ts72-824 | 26 | 1.70 | 1.00 | ± 0.06 | 0.07 |

Table A-14. Mean height and maturity of 50 soybean lines when grown in low- versus high-stress nursery environments.

| Line/Group | Pedigree | Height | | Maturity | |
|---|---|---|---|---|---|
| | | LS+ | HS+ | LS | HS |
| | | ----cm---- | | --days*-- | |
| Top Group (Superior) | | | | | |
| TN82-238 | Essex x Hodgson | 90 | 52 | 32 | 31 |
| TN82-239 | Essex x Hodgson | 95 | 46 | 33 | 30 |
| TN82-242 | Essex x Hodgson | 90 | 50 | 25 | 24 |
| TN82-243 | Essex x Hodgson | 92 | 53 | 30 | 32 |
| TN82-244 | Essex x Hodgson | 91 | 50 | 31 | 31 |
| TN82-252 | J74-45 x Ts72-824 | 97 | 55 | 34 | 28 |
| TN82-258 | J74-40 x Ts72-824 | 84 | 48 | 39 | 38 |
| TN82-261 | J74-40 x Ts72-824 | 86 | 51 | 40 | 38 |
| TN82-262 | Essex x (Bay x N73-520) | 91 | 48 | 35 | 29 |
| TN82-264 | Essex x (Bay x N73-520) | 81 | 44 | 30 | 24 |
| TN82-265 | Essex x (Bay x N73-520) | 95 | 51 | 41 | 37 |
| TN82-267 | Essex x (Bay x N73-520) | 95 | 50 | 36 | 35 |
| TN82-268 | Essex x (Bay x N73-520) | 78 | 41 | 25 | 22 |
| TN82-269 | Essex x (Bay x N73-520) | 77 | 44 | 25 | 23 |
| TN82-273 | Centennial x J74-45 | 103 | 52 | 44 | 40 |
| TN82-275 | Centennial x J74-45 | 101 | 54 | 50 | 39 |
| Middle Group (Non-Superior) | | | | | |
| TN82-230 | Essex x (Forrest x OK963) | 89 | 52 | 35 | 33 |
| TN82-231 | Essex x (Forrest x OK963) | 86 | 51 | 32 | 32 |
| TN82-232 | Essex x (Forrest x OK963) | 87 | 49 | 31 | 28 |
| TN82-233 | Essex x (Forrest x OK963) | 91 | 50 | 30 | 29 |
| TN82-234 | Essex x (Forrest x OK963) | 102 | 53 | 33 | 34 |
| TN82-236 | Essex x (Forrest x OK963) | 94 | 55 | 37 | 32 |
| TN82-240 | Essex x Hodgson | 88 | 52 | 32 | 31 |
| TN82-241 | Essex x Hodgson | 93 | 52 | 31 | 27 |
| TN82-245 | Essex x Hodgson | 93 | 61 | 31 | 35 |
| TN82-255 | J74-40 x Ts72-824 | 89 | 50 | 42 | 38 |
| TN82-263 | Essex x (Bay x N73-520) | 91 | 55 | 47 | 41 |
| TN82-266 | Essex x (Bay x N73-520) | 89 | 55 | 42 | 37 |
| TN82-270 | Centennial x J74-45 | 91 | 49 | 44 | 41 |
| TN82-272 | Centennial x J74-45 | 91 | 46 | 32 | 27 |
| TN82-274 | Centennial x J74-45 | 107 | 54 | 49 | 41 |
| TN82-276 | Centennial x J74-45 | 90 | 55 | 44 | 42 |
| Bottom Group (Non-Superior) | | | | | |
| TN82-235 | Essex x (Forrest x OK963) | 96 | 54 | 39 | 38 |
| TN82-237 | Essex x (Forrest x OK963) | 90 | 47 | 40 | 37 |
| TN82-246 | J74-45 x Ts72-824 | 86 | 50 | 30 | 26 |
| TN82-247 | J74-45 x Ts72-824 | 82 | 52 | 31 | 28 |
| TN82-248 | J74-45 x Ts72-824 | 89 | 49 | 31 | 30 |
| TN82-249 | J74-45 x Ts72-824 | 78 | 46 | 31 | 27 |
| TN82-250 | J74-45 x Ts72-824 | 92 | 52 | 35 | 33 |

Table A-14. (continued)

| Line/Group | Pedigree | Height LS | Height HS | Maturity LS | Maturity HS |
|---|---|---|---|---|---|
| TN82-251 | J74-45 x Ts72-824 | 87 | 52 | 31 | 25 |
| TN82-253 | J74-45 x Ts72-824 | 84 | 50 | 36 | 36 |
| TN82-254 | J74-40 x Ts72-824 | 95 | 60 | 44 | 41 |
| TN82-256 | J74-40 x Ts72-824 | 90 | 50 | 37 | 35 |
| TN82-257 | J74-40 x Ts72-824 | 95 | 53 | 41 | 40 |
| TN82-259 | J74-40 x Ts72-824 | 117 | 66 | 38 | 35 |
| TN82-260 | J74-40 x Ts72-824 | 91 | 50 | 38 | 38 |
| TN82-271 | Centennial x J74-45 | 93 | 56 | 47 | 42 |
| TN82-277 | Centennial x J74-45 | 101 | 53 | 47 | 40 |
| Check | | | | | |
| CULTIVAR | Essex | 76 | 42 | 31 | 31 |
| CULTIVAR | Forrest | 90 | 58 | 36 | 34 |

+LS = Low-Stress Site; HS = High Stress Site

*Days after August 31

# VITA

Wayne Francis Whitehead was born October 16, 1952 in New Orleans, Louisiana. He received his primary and secondary education in Madison County, Alabama. He graduated from Madison County High School in Gurley, Alabama in June 1972.

In January of 1973, he enlisted in the U.S. Navy at Huntsville, Alabama. He was honorably discharged from the U.S. Naval Medical Corps in December of 1976 at San Francisco (Treasure Island), California.

In September of 1977, he entered the University of Alabama in Huntsville to pursue a degree in marine biology. Later that year he transferred to Alabama Agricultural and Mechanical University where he received his Bachelor of Science in Horticulture in July, 1981.

In September of 1981, he reentered the Alabama Agricultural and Mechanical University to pursue a Master of Science degree in Soil and Plant Science with a major in plant breeding. He received his Master's degree from the Alabama Agricultural and Mechanical University in December, 1983.

On March 10, 1984, he was married to Farzaneh Hasanalizadeh in Athens, Greece. In April of 1984, he entered the University of Tennessee in Knoxville to pursue a Doctor of Philosophy degree in Plant and Soil Science with a major in plant breeding and genetics.

On April 6, 1986, he was blessed with a healthy son named Reza Paul.

He received his Ph.D. from the University of Tennessee in June of 1988.