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MERRILL.

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STUDY OF SEED YIELD EFFICIENCY, HYBRID VIGOR, AND PHENOTYPIC CORRELATIONS IN GLYCINE MAX (L.) MERRILL

DISSERTATION

Presented in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in the Graduate School of The Ohio State University

By

Jagmohan Joshi, B.Sc.(Agric.), M.Sc.(Agric.)

* * *

The Ohio State University

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ACKNOWLEDGMENTS

I gratefully express my sincere appreciation to Dr. Paul E. Smith, my adviser, for his able guidance, constructive suggestions, encouragement and inspiration throughout the course of this investigation as well as during the preparation of the dissertation.

My thanks are expressed to Drs. Elton F. Paddock, Professor of Genetics and Leo E. Bendixen, Professor of Agronomy, OSU, who very kindly read the manuscript and offered valuable criticisms and very useful suggestions.

My thanks are also expressed to Mr. Wilbur F. Forester, Biometrics, Division of Cardiology, OSU, for his help in the statistical analyses and computer programming.

My thanks are also expressed to Mr. Elvin Davenport, Farm Manager, OSU, and Francis J. DeDourek, Phil Houchins and David E. Clark, for their help and cooperation in field work during the course of this investigation.

My thanks are expressed to Mr. Oswald Andrade, Department of Medicine, OSU, for his assistance in making the illustrations.

I am also thankful to my wife, Santosh, for her encouragement and care of our three children - Shalinn, Shushen, and Shailesh - and who worked during the entire period of my study here.

Finally, I am pleased to express appreciation and sincere gratitude to all who cheerfully cooperated and helped me to complete this work.
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INTRODUCTION

The soybean crop is an important one in the developed countries and has all the potentialities of becoming an important crop in the developing countries. This crop has a long history in China but in the United States its history is comparatively brief. Soybean acreage in the United States has been steadily increasing for the last twenty years. The area under soybean production was 14 million acres in 1950 and, at present, well exceeds 42 million acres. On the other hand, the area under maize production has gone down during the same period. In Ohio, the area under soybean production during 1950-59 was 1.2 million acres, and within eleven years it has increased to 2.5 million acres. The United States, during 1971, produced about 1,169 million bushels which accounted for about 60% of the world production of soybeans. Ohio produced 76 million bushels of soybeans during 1971 (Table 11).

Soybeans are responsive to photoperiod. All cultivated varieties fix atmospheric N symbiotically. This crop succeeds on nearly all types of soils that supply adequate water. Soybean seed is rich in protein and oil. On a dry weight basis the seed contains 40% protein and 21% oil. Nearly 90% of soybean oil is used in human foods, primarily in shortening and margarine and over 95% of the protein is used in animal feeds. Soybeans have more diverse uses than most grains. This crop occupies second place among the cash crops of Ohio and of the United States. It is first among oil-seed crops of the Western Hemisphere.
After World War II the demand for high protein feeds increased and created a demand for soybean-meal in the domestic market and a strong export demand for the crop. This demand resulted in rapid expansion of soybean production. Since the demand for soybean products is rising continuously, greater efforts must be made to improve average yield per acre.

The importance of genetics and breeding cannot be over-emphasized in improving crop yields. Soybean breeding programs in the United States have followed the usual procedure of introduction, selection, and hybridization. Soybean breeding programs have resulted in twenty-four improved varieties which are high in yield and oil content; resistant to lodging, shattering, and some diseases; good in seed quality, and adapted in maturity to various production areas. Progress in breeding is becoming increasingly difficult, however, because of an increased number of breeding objectives and because the gross gains in the breeding of this introduced crop for a new production area have been made. Thus, future gains will require more refined techniques and procedures.

Varieties with high seed yield efficiency should be used in breeding programs. An efficient variety can be characterized either by a high SYE ratio of mature seed weight to non-seed dry matter weight (above ground unthreshed weight of plant at maturity minus its seed weight) or by a steep slope in the regression of seed weight over non-seed dry matter weight. A SYE ratio or a steep slope indicates that a high proportion of plant dry matter weight is due to the dry matter weight of the seed. In an efficient plant more of the energy used in producing the plant is channeled into the production of seed.
Hybrid vigor has been noted by plant breeders throughout the history of plant breeding. Data on soybeans are not extensive because a relatively small number of hybrids has been produced on account of the difficulty in manipulating the flowers. As early as 1924, Wentz and Stewart (43) demonstrated the phenomenon of hybrid vigor in soybeans. Improvement in soybean seed yield by hybridization has not been utilized to the fullest extent. Only a small increase has been made in the United States during the past twenty years, in the average seed yield per acre of soybeans, as compared with maize. The average increase for soybeans and maize is 0.25 bushel and 1.00 bushel per acre, respectively. Although a significant role has been played by research work on production problems and development of better varieties, the increase in total production has been due mostly to an increased acreage. Many of the studies of hybrids have been made for genetic purposes. Hybrid vigor in soybeans cannot be utilized in the same way as in maize, because of the difficulty in making crosses. If in the F2 generation, plants could be found that were homozygous for all vigor promoting alleles for which the F1 was heterozygous, they would breed true for increased vigor. Hybridization also provides an opportunity for the plant breeder to create new variability from which selections may be made.

Plant breeders are constantly trying to improve the seed yield of soybeans but seed yield is a trait which is quantitative in nature and also is greatly influenced by environment. Therefore, soybean breeders are always looking for traits which are consistently associated with seed yield. Plant breeders are not helped much by correlations calculated from data within the same variety. Such phenotypic correlations
are due to concomitant variation in two characters, both of which vary as a result of the same cause, such as soil fertility. Since environmental variations are not inherited, the plant breeder cannot use them for purposes of selection. If, however, it is found that taller varieties are good seed yielders and shorter varieties are poor seed yielders; as a rule, a knowledge of this fact is of material benefit to the plant breeder. Such a phenotypic correlation between height and seed yield is mainly genetic. Phenotypic correlations should indicate the relative importance of several seed yield determinants in producing seed yield and the attribute or attributes upon which most attention should be given. Another problem which concerns the plant breeder is the correlation between the seed yield components themselves. No variety ranks first in all seed yield components. Generally, the situation is such that a variety ranks well in one or more attributes but low or medium in others. If seed yield attributes are inherited independently, the chances of securing a desired recombination type should be good. If they are associated and tend to stay together in the same way as they are in the parents, the probability of obtaining a desired recombination is decreased.

In the investigations reported herein, an attempt has been made to study the variation in SYE of ten soybean varieties, and to seek Hybrid vigor in some agronomic characters including Seed yield. An effort also has been made to study the phenotypic correlation between Seed yield and Non-seed dry matter weight. The correlations of other agronomic traits with Seed yield and the association among these traits also have been studied.
MATERIALS AND METHODS

The present investigation was conducted at The Ohio State University Farm, Columbus, Ohio, during the summers of 1970, 1971, and 1972. Ten varieties of soybeans, Aoda, Cayuga, Giant Green, Haboro, Kakote, Henry, Kent, Kura, Manchura, and Wayne, were selected for this purpose. The seed of Henry, Kent, and Wayne varieties were obtained locally and seed of the other varieties were obtained from the Regional Soybean Laboratory, Urbana, Illinois. These ten varieties differed in such characters as maturity, height, seed coat color, pubescence color, and yield. The genetic background of these varieties is given in Table 1 (5,6).

During the summer of 1970, 15 seeds of each variety were sown in rows 28 inches apart with a seed drill. In order to get maximum flowering range, the plantings were made four times at 10-day intervals. Seed was multiplied for the next crop and some crosses were made.

During the summer of 1971, F1 seeds along with their parents were started in the greenhouse. The seeds were sown in paper pots filled with a greenhouse soil mixture. The greenhouse planting was done on May 8, 1971. After 17 days, when plants were about 6 inches tall, the pots containing the plants were put in the field in accordance with the field plot plan.
<table>
<thead>
<tr>
<th>Variety</th>
<th>Foreign Name or Parentage</th>
<th>Origin</th>
<th>Maturity Group</th>
<th>Flower Color</th>
<th>Pubescence Color</th>
<th>Seed Coat Color</th>
<th>Hilum Color</th>
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<td>1. Cayuga</td>
<td>No. 63</td>
<td>Manchuria, 1925</td>
<td>1</td>
<td>White</td>
<td>Tawny</td>
<td>Black</td>
<td>Black</td>
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<tr>
<td>2. Giant Green</td>
<td>Not known</td>
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<td>Purple</td>
<td>Tawny</td>
<td>Green</td>
<td>Black</td>
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<td>3. Habaro</td>
<td>Not known</td>
<td>USSR, 1906</td>
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<td>Purple</td>
<td>Gray</td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
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<td>4. Manchuria</td>
<td>Chin Yuan</td>
<td>Manchuria, 1910</td>
<td>1</td>
<td>Purple</td>
<td>Gray</td>
<td>Yellow</td>
<td>Light buff</td>
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<td>5. Hakote</td>
<td>Aoshiro Daizu</td>
<td>Japan, 1929</td>
<td>II</td>
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<td>Tawny</td>
<td>Yellow</td>
<td>Black</td>
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<td>6. Henry</td>
<td>Richland X Selection of (Dunfield X Illini)</td>
<td>U.S., 1960</td>
<td>II</td>
<td>Purple</td>
<td>Gray</td>
<td>Yellow</td>
<td>Gray</td>
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<td>7. Kura</td>
<td>Kura Kake Daizu</td>
<td>Japan, 1929</td>
<td>III</td>
<td>White</td>
<td>Tawny</td>
<td>Green</td>
<td>Black</td>
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<td>8. Wayne</td>
<td>(Lincoln, Richland, CNS) X Clark</td>
<td>U.S., 1931</td>
<td>III</td>
<td>White</td>
<td>Tawny</td>
<td>Yellow</td>
<td>Black</td>
</tr>
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<td>10. Aoda</td>
<td>AO Daizu</td>
<td>Japan, 1929</td>
<td>IV</td>
<td>Purple</td>
<td>Gray</td>
<td>Green</td>
<td>Buff</td>
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Field Plot Plan

The plot plan is shown in Figure 1. Each block consisted of three rows 28 inches apart. In each block each F\textsubscript{1} plant of an individual cross was placed in the middle row along with each of the parent varieties in the side rows. The place of a given F\textsubscript{1} in the middle row was determined through randomization. In the two side rows the position of male and female was also determined by randomization. The distance between plants within each row was 36 inches.

In 1972, the plot plan was the same as in 1971. The F\textsubscript{1} seeds along with their parents were sown directly in the field. In the case of parental seeds, three seeds of each parent were sown per hill and at a later date the two extra plants were cut below the cotyledonary level, thus, only one plant remained per hill.

F\textsubscript{2} Planting

All of the F\textsubscript{2} seeds of each cross were planted. These seeds were sown one foot apart and the distance between the rows was 28 inches. Parental varieties were also planted with the same spacing as the F\textsubscript{2} seed. Parental plants were sown with three seeds per hill and later thinned to one plant. The female and male parents were in the side rows and their position was determined by randomization.

Hybridization

The small size of the soybean flower makes artificial cross-pollination difficult. In emasculating the flower, the corolla and anthers were removed with a pair of small pointed forceps. If some anthers still remained on the flower, these were removed with a
Fig. 1. Field plot plans for F1, F2, and parents.
dissecting needle. While removing the anthers, care was taken to keep from breaking them open and, thus, self-pollinating the flower. Care was also taken to keep from injuring the ovulary. After emasculating the flower, the desired pollen was applied to the stigma. After cross-pollinating, a small tag bearing a record of the cross was placed on the stem. The cross-pollinated flowers were checked after seven days for any new flowering buds. The new buds, if developed, were removed. The hybridity of all hybrids reported in this study was definitely proved by the dominance in $F_1$ or segregation in $F_2$ of certain characters, such as flower or pubescence color or seed characteristics.

**Statistical Methods**

1. Test of significance between two ratios:

   Student's $t$ test was used to determine whether a difference in mean SYE ratio between varieties was significantly different. One of the requirements in the Student's $t$ test is that the population should be normally distributed, but in this case the SYE ratio deviates slightly from normal distribution. However, the Student's $t$ test has great power and it is hoped that waiving the assumption of normality will not upset the results obtained by using this statistic. It may be noted, however, that the distribution of the ratios is unimodal and is only moderately skewed.

2. Tests of significance between two linear regression coefficients:

   Another approach to test the SYE of different varieties is whether the regression coefficients (regressions of seed yield over non-seed dry matter) of the varieties differ significantly from each other. For this purpose Chow's test (10) was used. This test took into account both the
slopes and the intercept. It is a more appropriate test for my purpose, however, because slope and intercept could not be examined independently in my data and because the ratios are, in fact, not normally distributed.

Statistical Model:

\[ Y_1 = a_1 + b_1 x_{1i} + u_1 \quad i = 1, \ldots, N_1 \quad (1) \]
\[ Y_2 = a_2 + b_2 x_{2i} + u_2 \quad i = 1, \ldots, N_2 \quad (2) \]

Where subscripts 1 and 2 refer to the two sets of observations and u's are the stochastic error terms, it is assumed that \( u_2 \) has the same normal distribution as \( u_1 \) with variance-covariance matrix \( \sigma^2 I \) an identity matrix of appropriate order.

3. Phenotypic Correlations:

Phenotypic correlations of some important agronomic characters with Seed yield and correlations among these characters were calculated. The step-wise multiple-regression method was used to calculate the relative importance of various traits associated with seed yield.

Traits Recorded

The following traits were recorded:

1. Plant height - The height of all F1's and parents from base to tip of main stem was recorded in centimeters. Average height for each variety was calculated.

2. Number of branches - The number of branches of each F1 and of the parents was recorded and the average number of branches for each variety was recorded.
3. Flowering - Flowering date of each F₁, F₂, and the parent was recorded when the first flower appeared on the plant.

4. Maturity - Maturity was taken by recording the date on which 95% of the pods were ripe and nearly all leaves had dropped.

5. Number of one-, two-, and three- or-more ovuled pods. These were counted on each plant and averaged for each variety. Undeveloped ovules were also taken into account while classifying the pods. For example, if a pod contained two seeds and one undeveloped ovule, it was counted as a 3-ovuled pod.

6. Total number of seeds per plant - The total number of seeds per plant was counted and the average was calculated for each variety.

7. Undeveloped ovules - These were calculated by subtracting the number of mature seeds per plant from the total number of ovules. Average was calculated for each variety.

8. Seed size - The seed size was recorded as the weight in grams of 100 seeds.

9. Unthreshed weight - The unthreshed weight of the plant includes the air-dry weight in grams of the main stem, branches, pods and all seeds. Plants were harvested at maturity at ground level and were kept in cloth bags. These cloth bags were hung in a shed for about 45 days. After 45 days, unthreshed weight of each plant was recorded in grams. The average was calculated for each variety.

10. Total seed yield - The weight of all seeds from each plant was recorded in grams. The average was calculated for each variety.
11. Non-seed dry matter weight - The total seed yield was subtracted from unthreshed weight of each plant. The average was calculated for each variety.

12. Seed yield to Non-seed dry matter weight ratio or Seed yield efficiency (SYE) was calculated as follows:

\[
SYE = \frac{\text{Seed yield}}{\text{Unthreshed weight} - \text{Seed yield}}
\]

The average was calculated for each variety.

13. Podding height - The length of the stem from base to the first podded node was measured, and average podding height was calculated. The podding height is an important criterion in assessing harvest loss.
Glycine max (L.) Merrill (soybean) belongs to the family Leguminosae, subfamily Papilionoideae and the genus Glycine L. (32). Glycine ussuriensis Regel and Maack is the wild progenitor of the cultivated form G. max (25). Both species have forty chromosomes. They behave as diploids and are cross fertile. Their hybrids also have normal fertility.

The origin of the cultivated soybean is unknown but Nagata (28) postulated that the cultivated form was introduced into Japan via Korea where it had been introduced directly from North China during 200 B.C. to the third century. The first mention of the soybean being brought to the Western Hemisphere was in the writings of Engelbert Kaempfer, in 1712 (4). In the U.S.A., soybeans were first produced in 1804 in Pennsylvania, but it was not until 1898 that the U.S. Department of Agriculture began making introductions from Asiatic countries (3,9).

Soybeans are self-pollinated and produce many more flowers than pods. The shedding of 75% or more of the flowers is not uncommon. Flower and pod sheddings are not due to a lack of viable pollen (38) nor to lack of fertilization. Natural outcrossing also occurs though the species is naturally self-pollinated. The amount of natural outcrossing is about 0.5% for plants in adjacent rows and 1% for plants grown in close contact (14).
Artificial crossing of soybeans is very difficult. Local environmental conditions, including weather and insects, determine the time of day when crossing is most successful. Pollinations in mid or late afternoon are usually most successful. The percentage of successful crosses varies greatly from time to time. Low night temperature, amount of moisture, manipulation of photoperiod, and insects have been observed to influence the success of crosses. Ten to 15% of the crosses can be expected to be successful (39).

Some soybean varieties are indeterminate in growth habit and some are determinate. Indeterminate varieties increase in height by two to four times after flowering begins, whereas determinate varieties increase very little, if at all, after flowering. This character is controlled by a single gene pair, Dt dt, with indeterminate type being dominant (47,48).

About four to five weeks after emergence, when the plant has produced several trifoliolate leaves, pubescence color can be seen on the plant. In most varieties, pubescence is abundant on leaf, stem, and pod. The pubescence color is either tawny or gray. Tawny color is due to a brown pigment in most of the hairs, and gray is due to the absence of the brown pigment from the hairs. The difference in the pubescence color was inferred to be due to a single locus with tawny pubescence (T) dominant to gray (t) (44), but later some reports of unusual segregation of pubescence color were published. Some varieties such as Grant carry T, but intermediate or light tawny pubescence color is present, whereas others like Kingwa have T with a completely gray pubescence color. Consequently, the segregation of pubescence color was reviewed
again by Probst (31). He found that pubescence color is controlled by several gene pairs instead of one as had been suggested by Woodworth (44). It appears that genes at other loci modify or suppress the effect of T on pubescence color, but no generally accepted hypothesis has been published.

The flower color of most soybean varieties is either white or purple. Flower color is governed by a single gene pair with purple (W₁) dominant to white (w) (36,45). There are a few varieties, such as Laredo and Tanner, which have bicolor flowers. These flowers have purple areas near the base of the standard and the remainder of the corolla is white. The inheritance of this dilute purple type involves two loci (W₃W₃ and W₄W₄) which influence the intensity of purple (16). It appears that w₃w₃W₄- is the most common genotype and it produces the typical purple flower color. Genotype W₃-W₄- produces dark purple flowers, while W₃-w₄w₄ flowers are dilute purple. When the genotype is w₃w₃ W₄W₄ the flowers are white or nearly white. With w₁w₁ the flowers are always white, i.e., the effects of W₃w₃ and W₄w₄ are noticed only in W₁-genotypes (16).

Maturity is an important factor in soybean production. Soybean varieties can be classified as early, intermediate, and late maturing, depending upon the number of days taken to mature. Newly formed soybean seed contains nearly 90% moisture (34). Early in the bean-filling period and again as the bean matures, the moisture content decreases rapidly to 65-70%. Further reduction in moisture content of seed is slow and it reaches 60-65% while the seed accumulates dry matter and grows in size. When dry matter accumulation ends, moisture content in one to two weeks declines to 10-15%. The seed continues to accumulate
dry matter after the leaves of the plant begin to lose chlorophyll and turn yellow. The seed crop finally reaches its maximum dry weight when all the leaves are yellow and half of them have fallen from the plant (34). The mode of inheritance of maturity is complex. Singh and Anderson (35) reported that a few major genes and a number of minor genes govern this trait. They also reported evidence for dominance of earliness in some crosses and for dominance of lateness in other crosses. Woodworth (45), while studying segregating populations, reported that a tall, luxuriant, and late-maturing type was governed by a dominant gene (S), and a short, compact, and early type by the recessive allele(s).

As the soybean plant reaches maturity, there is a tendency for the pods to shatter. Shattering of pods varies from one variety to another. Most currently-grown varieties have been selected for a high degree of shatter resistance. It appears that two factor pairs are involved in shattering tendency. Shattering (Sh2) of wild soybeans was reported to be dominant to the nonshattering (sh2) of a Japanese variety (27). However, Morse and Carter (26) reported that the nonshattering (Sh1) of P.I. 22876 was dominant to the shattering (sh1) of Medium green.

The genetics of quantitative characters in soybeans and the linkage of genes conditioning quantitative traits have been studied widely in recent years. Some of the important objectives of soybean breeding are high yield, suitable maturity, standing ability, disease resistance, and quality. All of these traits have been found to have complex genetic mechanisms. Johnson and Bernard (18) summarized the situation when they indicated little, if anything, is known about the distribution on the chromosomes of genes conditioning quantitative characters in soybean.
Gates et al. (11) were of the opinion that linkage was of significant importance for flowering time, height, and yield but not for maturity, time of flowering to maturity, seed weight, oil percentage, and lodging.

Performance data of F₁ hybrids and parents are not extensive. This may be due to the fact that crossing in soybeans is tedious and the percentage of successful crossings is only 10 to 15. Even when a cross is successful, the crossed pod generally yields only one seed. Large numbers of F₁ seed are required for field testing to compensate for the loss because some seeds may not germinate and others may be taken out by birds. It has been found by many investigators that F₁ is superior over the high parent in seed yield and plant height. There are very few instances in which hybrid vigor of seed size has been noticed (39,43,48). Time of flowering was studied by Veatch (39). He observed that 11 out of 15 F₁'s flowered as late as the late parent or later. Seed yield, number of seeds, plant weight and total stem and branch length seem to be the best criteria of hybrid vigor in their soybeans. There is a marked variation in the expression of hybrid vigor among different crosses. Transgressive segregation also occurs in the case of seed yield, seed number, height of plant, and days from planting to flowering. Hybrid vigor and transgressive segregation may be due to partial dominance of growth factors having a cumulative effect (39). Weiss et al. (42) evaluated 17 crosses in greenhouse and in field. Out of 17 crosses, 10 gave significantly higher yields than their high-yielding parent under greenhouse conditions; whereas, under field conditions only 9 of the 17 crosses outyielded their high-yielding parent. There was, however, a distinct difference between the performance of the F₁, under these two conditions. The average
increase in yield above that of their high parent was 32.2% in the
greenhouse and 14.5% in the field. Also, the maturity of the F₁'s was
intermediate between the maturities of the parents. Kalton (21)
compared four F₁'s with their respective parents for two years. He
observed hybrid vigor in all four crosses in one year, but in only two
crosses in the other year. He also noted that F₁'s varied in maturity
and height from intermediate between the two parents to later and taller
than the latest and tallest parent. Leffel and Weiss (23) studied the
hybrid vigor (superiority of F₁ over high parent) in seed yield and
plant height. Out of ten parental lines, lines 1, 2, and 3 were the
earliest, shortest, and lowest yielding. They did not observe
significant hybrid vigor in maturity. However, 14 F₁'s showed signifi-
cant hybrid vigor in yield and 10 F₁'s in height. According to
Johnson and Bernard (18), the maturity of F₁'s is in general inter-
mediate but maturity also influences the expression of hybrid vigor in
yield and height. Maturity, yield, and height are positively inter-
correlated. Environmental conditions may favor either early or late
maturing plants, which makes genetic studies on maturity more
complicated and difficult.

Environmental conditions could favor the performance of the
intermediate F₁ from an early x late cross, when there is a consider-
able spread in maturity between the two parents. Brim and Cockerham (7)
examined seedling F₁'s from two crosses in drilled sowings at two
locations over a two-year period. The mean F₁ performance of both
crosses was significantly higher than the mean of parents in maturity
(lateness), unthreshed weight, seed weight, and yield, but for only one
of the crosses in height. The performance of $F_1$ was considerably
greater than that of the high parent for yield, height, and unthreshed
weight in one population, but only for yield in the other.

The performance of $F_1$ crosses deviates consistently from that of
the mean of both parents or of the high parent for characters such as
height and yield. Johnson and Bernard (18) are of the opinion that
some type of gene action in addition to strict additivity seems to be
indicated. Besides the effects of maturity on height, three other
gene pairs, namely $S$ (tall, late plant), $s$ (short, early plant), $Dt$
(indeterminate stem), $dt$ (determinate stem) and $Se$ (pedunculate
inflorescence), $se$ (subsessile inflorescence) affect the height of the
soybean plant. It appears that the $S$ $s$ gene pair controlling tall,
late plant or short, early plant acts through its effect on maturity.
These three gene pairs are known to interact in certain ways and other
apparent interactions have not been worked out genetically. Certain
characters such as seed size, oil content, and protein content which
are less influenced by maturity, do not have hybrid vigor. This
indicates that maturity may be a factor in the observations of hybrid
vigor in yield and height.

Veatch (39), studied the correlation between a character of the
hybrids and the parental average for that character. He observed that
the correlation coefficient ($r$) is higher when a character of the
hybrid is correlated with the parental average, than when with the
higher parent. However, the number of days to flowering gave a higher
correlation with the late flowering parent.
Woodworth (48) reported that 26 varieties differed greatly in average number of nodes per plant, pods per node, seeds per pod, percentage of aborted seed, unit seed weight, and yield per plant. He further observed that, in general, characters were independent of each other and only low percentage of aborted seeds, number of seeds, and high unit seed weight were highly associated with yield. Weatherspoon and Wentz (40) examined 237 strains for plant height as well as for all of the characters considered by Woodworth (48). They reported that plant height, nodes per plant, pods per plant, and pods per node were significantly correlated with yield. Multiple correlations between yield and combinations of characters were estimated and a correlation of 0.58 was obtained between yield and the combination of height, nodes per plant, pods per plant, aborted seed, and seed size. They concluded that the number of pods per plant, height, and seed size were by far the most important characters and the others gave very little additional information concerning yield. Ma (24) conducted two experiments involving 16 and 24 varieties in successive years and reported that the number of pods per plant, percentage of aborted seeds, seed size, number of seeds per pod, and percentage of developed pods differed significantly. He further observed that associations among characters were not consistent although the experiments had ten varieties in common. In the first experiment, yield was associated only with percentage of developed pods and number of seeds per pod; whereas, in the second year, yield was associated with seed size.

Weber and Moorthy (41) found substantial positive correlations between yield and maturity, height, and seed weight.
Yoshino et al. (49) studied 11 crosses in F$_2$. They estimated correlations between yield and number of branches, number of pods, plant height, and flowering time. They reported that the magnitude of the correlations varied from cross to cross.

Van Schaik and Probst (37) reported correlations between number of flowers per node and peduncle length, pods per node, and percent shedding in F$_2$'s of six crosses. They found that correlations between flowers per node and peduncle length ranged from 0.81 to 0.92; between flowers per node and pods per node from -0.04 to 0.56; and between flowers per node and percent shedding from 0.33 to 0.89.

Johnson and Bernard (18) are of the opinion that the reported correlations do not offer any limitations to breeding progress except for the serious limitations imposed by the negative association between protein and oil. In Northern latitudes, where early maturity is a necessity, the negative correlation between height and earliness and the positive correlation between height and yield have constituted definite limitations in practice. The negative correlation between height and lodging may be more serious in Southern than in Northern Latitudes where height is influenced by early maturity.

Johnson et al. (19) found that selection based on maturity, seed weight, or resistance to shattering was approximately 50% as effective in improving yield as selection based on yield alone. According to Hanson and Weber (15), the number of pods, lodging, plant height, and maturity contributed most to the visual concept of yield. Anand and Torrie (1), and Kwon and Torrie (22) observed that tallness, late
maturity, and susceptibility to lodging were associated with greater yield per acre and those factors were 50% as efficient as selection based on yield alone. These results and low heritability of yield, suggest that a breeder may best advance lines in early generations based on performance of traits other than yield itself.

The multiple correlations of certain plant traits with seed yield led to the idea of selection indices. Weatherspoon and Wentz (40) were the first to suggest such an approach. Johnson et al. (19) found that 95% of the progress expected from selection for yield could be achieved by selecting for fruiting period plus seed weight. When selection for resistance to lodging was also made along with fruiting period and seed weight, progress to the extent of 108% could be achieved. Hanson and Johnson (13), and Brim and Mason (8), however, emphasized the importance of correct estimates of genotypic variances, covariances and judicious use of selection indices.
EXPERIMENTAL RESULTS

The results obtained have been presented in Table 12 and under the following headings:

A. Seed Yield Efficiency (SYE)
B. Hybrid Vigor
C. Phenotypic Correlations
D. Transgressive Segregation

A. Seed Yield Efficiency (SYE)

Seed yield efficiency was measured as the ratio of Seed yield to Non-seed dry matter weight as well as the regressions of Seed yield over Non-seed dry matter weight for the different varieties. It is clear from Table 2 that Kent produced the highest Seed yield (59.0 grams) and Non-seed dry matter weight (40.2 grams) per plant, but the SYE of this variety was only 1.42. The highest SYE was observed in Wayne. In this case the SYE was 1.52, but this variety was the second best in Seed yield as well as in Non-seed dry matter production. Wayne, however, produced a higher SYE as compared to Kent. This difference in SYE between Wayne and Kent was statistically significant at the 5% level (Table 4). Cayuga produced 14.1 grams of seed and 9.3 grams of Non-seed dry matter. The SYE of Cayuga was 1.51. This was the second best variety as far as SYE was concerned though it gave poor seed yield.

It was also clear from Figure 2 that high-yielding varieties might not be the most efficient seed producers. The lowest SYE was 1.28 for Giant Green and Aoda. Giant Green produced 13.0 grams of seed and
TABLE 2

Average Seed Yield, Non-seed Dry Matter Weight, and Seed Yield to Non-seed Dry Matter Ratio (SYE) per Plant for Each Variety

<table>
<thead>
<tr>
<th>No.</th>
<th>Variety</th>
<th>Seed Yield (gm)</th>
<th>Non-seed Dry Matter (gm)</th>
<th>SYE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>KENT</td>
<td>59.0</td>
<td>40.2</td>
<td>1.42</td>
</tr>
<tr>
<td>2</td>
<td>WAYNE</td>
<td>47.6</td>
<td>30.8</td>
<td>1.52</td>
</tr>
<tr>
<td>3</td>
<td>HENRY</td>
<td>28.0</td>
<td>21.4</td>
<td>1.32</td>
</tr>
<tr>
<td>4</td>
<td>AODA</td>
<td>27.2</td>
<td>20.6</td>
<td>1.28</td>
</tr>
<tr>
<td>5</td>
<td>KURA</td>
<td>24.7</td>
<td>18.4</td>
<td>1.35</td>
</tr>
<tr>
<td>6</td>
<td>HABARO</td>
<td>19.7</td>
<td>13.1</td>
<td>1.44</td>
</tr>
<tr>
<td>7</td>
<td>HAKOTE</td>
<td>19.0</td>
<td>12.8</td>
<td>1.44</td>
</tr>
<tr>
<td>8</td>
<td>MANCHURIA</td>
<td>14.8</td>
<td>9.1</td>
<td>1.49</td>
</tr>
<tr>
<td>9</td>
<td>CAYUGA</td>
<td>14.1</td>
<td>9.3</td>
<td>1.51</td>
</tr>
<tr>
<td>10</td>
<td>GIANT GREEN</td>
<td>13.0</td>
<td>9.8</td>
<td>1.28</td>
</tr>
</tbody>
</table>
Fig. 2. Relative performance of 10 soybean varieties in Seed yield, Non-seed dry matter weight, and ratio (SYE) of Seed yield to Non-seed dry matter.
9.8 grams of Non-seed dry matter. But in the case of Aoda, though the ratio was 1.28, the amount of seed and Non-seed dry matter produced was much higher than Giant Green.

The number of observations for each variety, and the mean, standard deviation, and standard error are given in Table 3. Forty-five comparisons of the mean SYE of these varieties were made and the data are presented in Table 4. It was clear that significant differences in SYE existed between some varieties. Wayne was significantly superior to Kent (5% level), Kura (1% level), Henry (1% level), Giant Green (1% level), and Aoda (1% level). When Wayne was compared with Cayuga, Manchuria, Habaro, and Hakote, the differences were not statistically significant. Cayuga did not differ significantly from Manchuria, Habaro, Hakote, and Kent but was more efficient than Kura (1% level), Henry (1% level), Giant Green (5% level) and Aoda (1% level). Manchuria was more efficient than Henry but the comparison with other varieties was not significant. Habaro was a more efficient seed producer than Henry and this difference was statistically significant at the 1% level. Habaro also was significantly better than Aoda (5% level). All other comparisons between Habaro and other varieties were not statistically significant. Hakote was better than Henry and the difference was statistically significant at the 5% level. Kent, Kura, Giant Green and Aoda, when compared with Hakote did not produce significant differences in SYE. Kent gave higher SYE than Henry and the difference was statistically significant at the 5% level. No statistically significant differences were noted between Kent and Kura, Kent and Giant Green, or Kent and Aoda. Also the differences in SYE
### TABLE 3

Mean, Standard Deviation, and Standard Error of Seed Yield to Non-seed Dry Matter Ratio (SYE) for Different Varieties

<table>
<thead>
<tr>
<th>No.</th>
<th>VARIETY</th>
<th>OBSERVATIONS</th>
<th>X</th>
<th>SD</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>WAYNE</td>
<td>45</td>
<td>1.52</td>
<td>0.16795</td>
<td>0.02503</td>
</tr>
<tr>
<td>2</td>
<td>CAYUGA</td>
<td>9</td>
<td>1.51</td>
<td>0.12184</td>
<td>0.04061</td>
</tr>
<tr>
<td>3</td>
<td>MANCHURIA</td>
<td>7</td>
<td>1.49</td>
<td>0.42158</td>
<td>0.15934</td>
</tr>
<tr>
<td>4</td>
<td>HABARO</td>
<td>20</td>
<td>1.44</td>
<td>0.22696</td>
<td>0.05075</td>
</tr>
<tr>
<td>5</td>
<td>HAKOTE</td>
<td>9</td>
<td>1.44</td>
<td>0.23558</td>
<td>0.07852</td>
</tr>
<tr>
<td>6</td>
<td>KENT</td>
<td>39</td>
<td>1.42</td>
<td>0.24388</td>
<td>0.03905</td>
</tr>
<tr>
<td>7</td>
<td>'KURA</td>
<td>13</td>
<td>1.35</td>
<td>0.11486</td>
<td>0.03185</td>
</tr>
<tr>
<td>8</td>
<td>HENRY</td>
<td>46</td>
<td>1.32</td>
<td>0.13296</td>
<td>0.01960</td>
</tr>
<tr>
<td>9</td>
<td>GIANT GREEN</td>
<td>8</td>
<td>1.28</td>
<td>0.26175</td>
<td>0.09254</td>
</tr>
<tr>
<td>10</td>
<td>AODA</td>
<td>12</td>
<td>1.28</td>
<td>0.16431</td>
<td>0.04743</td>
</tr>
</tbody>
</table>

SD = Standard Deviation  
SE = Standard Error
<table>
<thead>
<tr>
<th></th>
<th>CAYUGA</th>
<th>MANCHURIA</th>
<th>HABARO</th>
<th>HAKOTE</th>
<th>KENT</th>
<th>KURA</th>
<th>HENRY</th>
<th>GIANT GREEN</th>
<th>AODA</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAYNE</td>
<td>0.169</td>
<td>0.344</td>
<td>1.586</td>
<td>1.217</td>
<td>2.212*</td>
<td>3.415**</td>
<td>6.306**</td>
<td>3.405**</td>
<td>4.417**</td>
</tr>
<tr>
<td>CAYUGA</td>
<td>0.136</td>
<td>0.865</td>
<td>0.792</td>
<td>1.070</td>
<td>3.135**</td>
<td>3.969**</td>
<td>2.370*</td>
<td>3.526**</td>
<td></td>
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<tr>
<td>MANCHURIA</td>
<td>0.398</td>
<td>0.302</td>
<td>0.620</td>
<td>1.145</td>
<td>2.193*</td>
<td></td>
<td>1.177</td>
<td>1.559</td>
<td></td>
</tr>
<tr>
<td>HABARO</td>
<td>0.000</td>
<td>0.305</td>
<td>1.319</td>
<td>2.691**</td>
<td></td>
<td>1.615</td>
<td>2.125*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAKOTE</td>
<td>0.223</td>
<td>1.196</td>
<td></td>
<td>2.153*</td>
<td></td>
<td>1.327</td>
<td>1.837</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KENT</td>
<td>0.994</td>
<td>2.394*</td>
<td>1.462</td>
<td></td>
<td>1.857</td>
<td></td>
<td></td>
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<tr>
<td>KURA</td>
<td>0.738</td>
<td></td>
<td>0.850</td>
<td></td>
<td>1.243</td>
<td></td>
<td></td>
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<tr>
<td>HENRY</td>
<td></td>
<td></td>
<td>0.667</td>
<td></td>
<td>0.884</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>GIANT GREEN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Denotes significance at 5% level.
**Denotes significance at 1% level.
between Kura and Henry, Kura and Giant Green, Kura and Aoda, Henry and Giant Green, Henry and Aoda, and Giant Green and Aoda were non-significant.

Another approach to identify the most efficient lines in producing seed weight per unit of non-seed dry matter was the analysis of regressions of seed weight over non-seed dry matter weight for the different varieties. Chow's (10) test provided this opportunity for testing regressions. This test took into account the slope and the intercept at the same time. This was an important criterion in this analysis as the two components of regression, i.e., slope and intercept could not be examined independently.

The linear regression equation \( y = ax + b \) was calculated for each variety and the data regarding slope and intercept have been given in Table 5 and in Figures 15, 16, and 17.

The regressions of Seed yield over Non-seed dry matter for each variety were analyzed statistically in accordance with Chow's test and \( F \) values for forty-five comparisons between regressions have been given in Table 6. It is clear from Table 6 that Wayne was significantly superior to Kent, Kura, Henry, and Aoda at the 1% level in producing more seed yield per unit of non-seed dry matter weight. When Wayne was compared with Cayuga, Manchuria, Habaro, Hakote, and Giant Green, no statistically significant differences were observed. Hakote and Giant Green were significantly better (1% level) than Cayuga. All other comparisons between Cayuga and the other varieties were not statistically significant. Hakote produced more seed yield per unit of non-seed dry matter weight than Manchuria and this difference was
<table>
<thead>
<tr>
<th>No.</th>
<th>VARIETY</th>
<th>SLOPE</th>
<th>INTERCEPT</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>HAKOTE</td>
<td>2.503</td>
<td>-13.413</td>
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<tr>
<td>2</td>
<td>GIANT GREEN</td>
<td>2.158</td>
<td>-8.214</td>
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<tr>
<td>3</td>
<td>MANCHURIA</td>
<td>1.960</td>
<td>-2.978</td>
</tr>
<tr>
<td>4</td>
<td>HABARO</td>
<td>1.682</td>
<td>-2.436</td>
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<td>5</td>
<td>CAYUGA</td>
<td>1.629</td>
<td>-1.022</td>
</tr>
<tr>
<td>6</td>
<td>KENT</td>
<td>1.626</td>
<td>-6.314</td>
</tr>
<tr>
<td>7</td>
<td>WAYNE</td>
<td>1.626</td>
<td>-3.075</td>
</tr>
<tr>
<td>8</td>
<td>AODA</td>
<td>1.455</td>
<td>-2.840</td>
</tr>
<tr>
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<td>KURA</td>
<td>1.125</td>
<td>3.935</td>
</tr>
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<td>4.229</td>
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<tr>
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<td>MANCHURIA</td>
<td>HABARO</td>
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<td>--------</td>
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</tr>
<tr>
<td>WAYNE</td>
<td>0.948</td>
<td>2.290</td>
<td>0.838</td>
</tr>
<tr>
<td>CAYUGA</td>
<td>2.222</td>
<td>0.505</td>
<td>9.372**</td>
</tr>
<tr>
<td>MANCHURIA</td>
<td>2.490</td>
<td>8.610**</td>
<td>3.522*</td>
</tr>
<tr>
<td>HABARO</td>
<td>2.584</td>
<td>3.904*</td>
<td>11.812**</td>
</tr>
<tr>
<td>HAKOTE</td>
<td>2.673</td>
<td>8.812**</td>
<td>5.163**</td>
</tr>
<tr>
<td>KENT</td>
<td>1.896</td>
<td>22.313**</td>
<td>1.340</td>
</tr>
<tr>
<td>KURA</td>
<td>0.332</td>
<td>5.430*</td>
<td>1.686</td>
</tr>
<tr>
<td>HENRY</td>
<td>4.743*</td>
<td>5.034**</td>
<td></td>
</tr>
<tr>
<td>GIANT GREEN</td>
<td>2.044</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Denotes significance at 5% level.
** Denotes significance at 1% level.
statistically significant at the 1% level. Giant Green was also
significantly (5% level) better than Manchuria. Manchuria, however,
was more efficient as compared to Kent, Kura, Henry and Aoda. There
was no statistically significant difference between Manchuria and Habaro.
Habaro, however, was significantly superior to Kent (5% level), Kura
(1% level), and Henry (1% level). The differences in the performances
of Habaro and Hakote, Habaro and Giant Green, and Habaro and Aoda were
not statistically significant. Hakote was superior to Kura and Henry
at the 1% level of significance, but when Hakote was compared with Kent,
Giant Green, and Aoda, the differences were not statistically signifi-
cant. Kent was a more efficient producer of seed yield per unit of non-
seed dry matter weight than Henry, but the differences between Kent and
Kura, Kent and Giant Green, and Kent and Aoda were not statistically
significant. Giant Green was significantly superior to Kura at the 5%
level. There were no significant differences between Kura and Henry
or Kura and Aoda. Henry produced significantly less seed yield per unit
of non-seed dry matter weight as compared to Giant Green (5% level) and
Aoda (1% level). The difference between the performance of Giant Green
and Aoda was not statistically significant.

B. Hybrid Vigor:

It is a necessity to grow F₁ to study hybrid vigor. One F₁ plant
of Aoda x Kent was produced. The F₁ plant had tawny pubescence color.
This was the first indication that this was a successful cross. Seed
characteristics were studied after harvesting. Coat color of the F₂
seed was green and the hilum color was black. This confirmed the
genuineness of this particular cross.
The performances of F₁, and the parents, are given in Table 7.

**Non-seed Dry Matter:**

The F₁ plant produced 48.4 grams of non-seed dry matter, whereas the female and male parents produced only 25.3 and 27.5 grams, respectively. The F₁ produced 83.3% more non-seed dry matter as compared to the parental average (26.4 gm). A 76% increase was observed when the F₁ was compared with the high parent (Fig. 3). A considerable amount of hybrid vigor was expressed in this trait.

**Seed Yield:**

The F₁ plant produced 59.1 grams of seed per plant as compared to 29.7 grams by the female parent (Aoda) and 39.4 grams by the male parent (Kent). The F₁ represents 70.8% more when compared with the parental average (34.6 grams), and 50% more than the high parent (39.4 grams) (Fig. 3). A considerable amount of hybrid vigor is evident.

**Seed Yield/Non-seed Dry Matter Ratio (SYE):**

This ratio for the F₁ was 1.22. The female and male parents had ratios of 1.17 and 1.43, respectively. The F₁ had a slight increase over the low parent. On the other hand, the performance of the F₁ shows a 6.2% and 14.7% decrease, respectively, when compared with the parental average (1.30) and the high parent (1.43). It appears that this may be a case of partial dominance. The F₁ ratio (1.22) is slightly better than the low parent (1.17) (Fig. 4).
**TABLE 7**
Performance of F$_1$ (Aoda x Kent), Female (Aoda), and Male (Kent) Parents

<table>
<thead>
<tr>
<th>No.</th>
<th>Character</th>
<th>$\varphi$ Parent</th>
<th>$\sigma$ Parent</th>
<th>Parental Average</th>
<th>$F_1$</th>
<th>% Increase (+) or Decrease (-) over Parental High Parent</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Non-seed dry matter weight (gm)</td>
<td>25.3</td>
<td>27.5</td>
<td>26.4</td>
<td>48.4</td>
<td>+83.3 +76.0</td>
</tr>
<tr>
<td>2.</td>
<td>Seed yield (gm)</td>
<td>29.7</td>
<td>39.4</td>
<td>34.6</td>
<td>59.1</td>
<td>+70.8 +50.0</td>
</tr>
<tr>
<td>3.</td>
<td>SYE (Ratios)</td>
<td>1.17</td>
<td>1.43</td>
<td>1.30</td>
<td>1.22</td>
<td>-6.2 -14.7</td>
</tr>
<tr>
<td>4.</td>
<td>Days from flowering to maturity</td>
<td>97</td>
<td>112</td>
<td>104.5</td>
<td>108</td>
<td>+3.5 -3.6</td>
</tr>
<tr>
<td>5.</td>
<td>Plant height (cm)</td>
<td>35.0</td>
<td>58.5</td>
<td>46.8</td>
<td>64.5</td>
<td>+37.8 +10.3</td>
</tr>
<tr>
<td>6.</td>
<td>Number of branches</td>
<td>18</td>
<td>14</td>
<td>16</td>
<td>17</td>
<td>+6.3 -5.6</td>
</tr>
<tr>
<td>7.</td>
<td>Unthreshed weight (gm)</td>
<td>55.0</td>
<td>69.0</td>
<td>62.0</td>
<td>107.5</td>
<td>+73.4 +55.9</td>
</tr>
<tr>
<td>8.</td>
<td>One-ovuled pods</td>
<td>24</td>
<td>10</td>
<td>17</td>
<td>28</td>
<td>+64.7 +16.7</td>
</tr>
<tr>
<td>9.</td>
<td>Two-ovuled pods</td>
<td>53</td>
<td>33</td>
<td>43</td>
<td>127</td>
<td>+195.4 +139.6</td>
</tr>
<tr>
<td>10.</td>
<td>Three- or more-ovuled pods</td>
<td>0</td>
<td>73</td>
<td>36.5</td>
<td>36</td>
<td>-1.4 -50.7</td>
</tr>
<tr>
<td>11.</td>
<td>Total pods/plant</td>
<td>77</td>
<td>116</td>
<td>96.5</td>
<td>191</td>
<td>+97.9 +64.7</td>
</tr>
<tr>
<td>12.</td>
<td>Number of seeds/plant</td>
<td>96</td>
<td>226</td>
<td>161</td>
<td>273</td>
<td>+69.6 +20.8</td>
</tr>
<tr>
<td>13.</td>
<td>Number of undeveloped ovules</td>
<td>34</td>
<td>69</td>
<td>51.5</td>
<td>117</td>
<td>+127.2 +69.6</td>
</tr>
<tr>
<td>14.</td>
<td>Number of seeds/pod</td>
<td>1.3</td>
<td>2.0</td>
<td>1.7</td>
<td>1.4</td>
<td>-17.7 -30.0</td>
</tr>
<tr>
<td>15.</td>
<td>Seed size (wt/100 seeds) (gm)</td>
<td>30.0</td>
<td>17.8</td>
<td>23.9</td>
<td>22.3</td>
<td>-6.7 -25.7</td>
</tr>
<tr>
<td>16.</td>
<td>Poding height (cm)</td>
<td>7.0</td>
<td>4.0</td>
<td>5.5</td>
<td>9.5</td>
<td>+72.7 +35.7</td>
</tr>
</tbody>
</table>
Fig. 3. Relative performance of F₁ and its female (Aoda) and male (Kent) parents in Non-seed dry matter, Seed yield, Unthreshed weight, and Seed size.
Fig. 4. Relative performance of F₁ and its female (Aoda) and male (Kent) parents in Seeds per pod and SYE.
Days from Flowering to Maturity:

The F1 plant took 108 days to mature, whereas, the female and male parents took 97 and 112 days, respectively. The F1 represents an increase of 3.5% over the parental average and a decrease of 3.6% over the high parent. This appears to be a case of partial dominance, lateness being partially dominant to earliness (Fig. 5).

Plant Height:

Height of the F1 plant (64.5 cm) was considerably increased (37.8%) over the parental average (46.8 cm). When compared with the high parent (58.5 cm), the F1 had an increase of 10.3%. Height of the female parent (Aoda) was 35.0 cm and the male parent (Kent) was 58.5 cm (Fig. 6). Some hybrid vigor was expressed in the height of the F1.

Number of Branches:

The F1 plant produced 17 branches which is an increase of 6.3% over the parental average. The male and female parents produced 14 and 18 branches, respectively. However, the F1 produced fewer branches in comparison to the high parent, a loss of 5.6% (Fig. 6). High number of branches was partially dominant in this case.

Unthreshed Weight:

Unthreshed weight of the F1 plant increased 73.4% over the parental average and 55.8% over the high parent. The F1 produced 107.5 grams, whereas the female and male parents weighed 55.0 and 69.0 grams, respectively. A considerable amount of hybrid vigor has been expressed in the F1 for unthreshed weight (Fig. 3).

One-ovuled Pods:

The F1 plant produced 28 one-ovuled pods, whereas the female and male parents produced only 24 and 10 pods, respectively. The F1 plant
Relative performance of F₁ and its female (Aoda) and male (Kent) parents in Total seeds, Days from flowering to maturity, and Undeveloped ovules.
Fig. 6. Relative performance of $F_1$ and its female (Aoda) and male (Kent) parents in Plant height, Branches, and Podding height.
had an increase of 64.7% over the parental average and an increase of 16.7 over the high parent (Fig. 7). Some hybrid vigor has been expressed in this trait.

Two-ovuled Pods:

The highest percentage increase was noted in this trait. The F$_1$ plant produced 127 two-ovuled pods and the female and male parents bore 53 and 33 two-ovuled pods, respectively. The F$_1$ plant represents an increase of 195.4% and 139.6% over the parental average and high parent respectively (Fig. 7). An appreciable amount of hybrid vigor was expressed in this trait.

Three- or-more-ovuled Pods:

The female parent did not produce any three- or-more-ovuled pods, whereas the male parent produced 73 such pods. The F$_1$ plant produced 36 pods which represented a decrease of 1.4% and 50.7% over the parental average and high parent, respectively (Fig. 7). Three- or-more-ovuled pods appear to be partially dominant.

Number of Pods per Plant:

The F$_1$ plant had 191 pods which represents an increase of 97.9% and 64.7% over the parental average and high parent, respectively. The female and male parents produced 77 and 116 pods, respectively (Fig. 7). A considerable amount of hybrid vigor was noted in this trait.

Number of Seeds Per Plant:

The F$_1$ plant produced 273 seeds, which is an increase of 69.6% over the parental average and an increase of 20.8% over the high parent. The female parent produced 96 and the male parent produced 226 (Fig. 5). Some hybrid vigor has been noted in this trait.
Fig. 7. Relative performance of $F_1$ and its female (Aoda) and male (Kent) parents in 1-Ovuled, 2-Ovuled, Three-or-more-ovuled pods, and Total pods.
Number of Undeveloped Ovules:

The number of undeveloped ovules was 34 in the female parent and 69 in the male parent but the F1 plant produced 117 undeveloped ovules. The F1 plant produced 127.2% and 69.6% more undeveloped ovules over the parental average and high parent, respectively (Fig. 5).

Number of Seeds per Pod:

The F1 plants had 1.4 seeds per pod, whereas the female and male parents produced 1.3 and 2.0, respectively. The F1 plant had 17.7% less seeds per pod than the parental average and 30.0% less than the high parent (Fig. 4).

Seed Size (Weight per 100 Seeds):

One hundred seeds of the female parent weighed 30.0 grams; whereas 100 seeds of the male parent weighed only 17.8 grams. This indicates that the female parent produced larger seeds than the male parent. The weight of 100 seeds in the case of the F1 plant was 22.3 grams. This represents a decrease of 6.7% and 25.7% over the parental average (23.9 grams) and high parent, respectively (Fig. 3). Large seed size appears to be partially dominant.

Pod Height:

The height of the lowest pod was 7.0 cm for the female parent and 4.0 cm for the male parent. Podding height for the F1 was 9.5 cm, which represents an increase of 72.7% and 35.7% over the parental average and high parent, respectively (Fig. 6). Some hybrid vigor was noted in this trait.
C. Phenotypic Correlations

Phenotypic correlations between yield attributes and yield, and correlations among the yield attributes themselves, were calculated. These correlation coefficients \((r)\) are given in Table 8. It was observed that Days from flowering to maturity (Fig. 8), Unthreshed weight (Fig. 9), Non-seed dry matter weight (Fig. 10), and Number of branches (Fig. 11), Pods (Fig. 12), Seeds, Undeveloped ovules, and Height (Fig. 13), all were significantly and positively correlated with Seed yield. All of the above-mentioned correlations were significant at the 1% level except the Number of branches, which was significant at the 5% level. It was further noted that some characters as Number of seeds per pod, Seed size (weight/100 seeds), Podding height, and SYE were not correlated with Seed yield.

Correlations Among Yield Attributes:

Days from flowering to maturity is significantly and positively correlated with Unthreshed weight, and Numbers of Branches, Pods, Seeds and Undeveloped ovules, and Non-seed dry matter weight. It was, however, noted that Days from flowering to maturity was not significantly correlated with Plant height. Unthreshed weight per plant was also positively correlated with Plant height, Non-seed dry matter weight, and Number of Branches, Pods, Seeds, and Undeveloped ovules. These correlation coefficients are significant at the 1% level. Plant height was also positively correlated with Non-seed dry matter weight and Numbers of pods, Number of seeds, Undeveloped ovules, at the 1% level of significance. It was, however, observed that Plant height was not significantly correlated with Number of branches. Number of branches
### TABLE 8
Correlation Coefficients (r) Among Different Characters

<table>
<thead>
<tr>
<th>Characters</th>
<th>UNTHRESHED WEIGHT</th>
<th>HEIGHT</th>
<th>NUMBER OF BRANCHES</th>
<th>NUMBER OF PODS</th>
<th>NUMBER OF SEEDS</th>
<th>UNDEVELOPED OVULES</th>
<th>NON-SEED DRY MATTER WEIGHT</th>
<th>SEED YIELD</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAYS FROM FLOWERING TO MATURITY</td>
<td>0.828**</td>
<td>0.502</td>
<td>0.899**</td>
<td>0.706*</td>
<td>0.580*</td>
<td>0.728**</td>
<td>0.848**</td>
<td>0.812**</td>
</tr>
<tr>
<td>UNTHRESHED WEIGHT</td>
<td>0.889**</td>
<td>0.739**</td>
<td>0.976**</td>
<td>0.929**</td>
<td>0.970**</td>
<td>0.970**</td>
<td>0.997**</td>
<td>0.999**</td>
</tr>
<tr>
<td>HEIGHT</td>
<td>0.518</td>
<td>0.934**</td>
<td>0.955**</td>
<td>0.931**</td>
<td>0.878**</td>
<td>0.878**</td>
<td>0.894**</td>
<td>0.894**</td>
</tr>
<tr>
<td>NUMBER OF BRANCHES</td>
<td>0.610*</td>
<td>0.472</td>
<td>0.608*</td>
<td>0.698*</td>
<td>0.777**</td>
<td>0.777**</td>
<td>0.712*</td>
<td>0.712*</td>
</tr>
<tr>
<td>NUMBER OF PODS</td>
<td>0.977**</td>
<td>0.960**</td>
<td>0.961**</td>
<td>0.961**</td>
<td>0.983**</td>
<td>0.983**</td>
<td>0.939**</td>
<td>0.939**</td>
</tr>
<tr>
<td>NUMBER OF SEEDS</td>
<td></td>
<td>0.918**</td>
<td></td>
<td>0.918**</td>
<td>0.908**</td>
<td>0.908**</td>
<td>0.965**</td>
<td>0.970**</td>
</tr>
<tr>
<td>UNDEVELOPED OVULES</td>
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<td></td>
<td></td>
<td>0.965**</td>
<td>0.970**</td>
<td>0.970**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NON-SEED DRY MATTER WEIGHT</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>0.992**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NUMBER OF SEEDS/POD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.428</td>
<td></td>
<td></td>
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<td>SEED SIZE</td>
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<td></td>
<td></td>
<td></td>
<td>-0.035</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PODDING HEIGHT</td>
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<td></td>
<td></td>
<td>-0.152</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEED YIELD EFFICIENCY (SYE)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.135</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*denotes significance at 5% level.

**denotes significance at 1% level.
Fig. 8. Correlation between Days from flowering to maturity and Seed yield in 10 soybean varieties. Values per plant.
Fig. 9. Relationship between Unthreshed weight and Seed yield in 10 soybean varieties. Values per plant.
Fig. 10. Relationship between Non-seed dry matter and Seed yield in 10 soybean varieties. Values per plant.

\[ r = 0.992 \]
\[ Y = 1.472X - 0.598 \]
Fig. 11. Relationship between Number of branches and Seed yield in 10 soybean varieties. Values per plant.

$r = 0.712$

$Y = 2.906X - 2.461$
Fig. 12. Correlation between Number of pods and Seed yield in 10 soybean varieties. Values per plant.

\[ r = 0.983 \]
\[ Y = 0.399X - 2.930 \]
Fig. 13. Relationship between Plant height and Seed yield in 10 soybean varieties. Values per plant.
was positively correlated with Non-seed dry matter weight at the 1% level of significance and with Number of pods and Undeveloped ovules at the 5% level of significance. Number of branches was not significantly correlated with Number of seeds. Number of pods gave a significant (1% level) positive correlation coefficient with Number of seeds, Number of undeveloped ovules, and Non-seed dry matter weight. Number of seeds per plant was positively correlated with Undeveloped ovules and Non-seed dry matter at 1% level of significance. Number of undeveloped ovules was also positively correlated with Non-seed dry matter weight at the 1% level of significance.

Plant characters which contribute most in improving seed yield have been listed in order of their importance in Tables 9 and 10. Unthreshed weight and Non-seed dry matter weight when considered together in the stepwise multiple regression analysis along with other characters gave a correlation coefficient of 1, after the selection of Unthreshed weight and Non-seed dry matter weight. Other characters which also had appreciable influence on yield could not be considered in this way. Therefore, it was desirable to evaluate the characters in two sets of data, one set with Non-seed dry matter weight and the rest of the characters (Table 9), excluding Unthreshed weight and the other set of data with Unthreshed weight and the rest of the characters (Table 10), excluding Non-seed dry matter weight. It was clear from Table 9 that substantial improvement in the correlation coefficient was made by Non-seed dry matter weight. A variability of 98.38% in yield is due to Non-seed dry matter. Number of pods per plant is the second important character which along with Non-seed dry matter weight improves the
### TABLE 9

Stepwise Multiple Regression of Different Characters with Seed Yield
(Unthreshed Wt. excluded)

<table>
<thead>
<tr>
<th>No.</th>
<th>DEPENDENT VARIABLE</th>
<th>r</th>
<th>$r^2$</th>
<th>% Increase in RSQ</th>
<th>Cumulative %</th>
<th>Std. Error of Estimate</th>
<th>F Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NON-SEED DRY MATTER WEIGHT</td>
<td>0.9919</td>
<td>0.9838</td>
<td>98.38</td>
<td>98.38</td>
<td>2.0515</td>
<td>486.7659</td>
</tr>
<tr>
<td>2</td>
<td>NUMBER OF PODS</td>
<td>0.9977</td>
<td>0.9953</td>
<td>1.15</td>
<td>99.53</td>
<td>1.1790</td>
<td>17.2221</td>
</tr>
<tr>
<td>3</td>
<td>DAYS FROM FLOWERING TO MATURITY</td>
<td>0.9983</td>
<td>0.9967</td>
<td>0.14</td>
<td>99.67</td>
<td>1.0757</td>
<td>2.4088</td>
</tr>
<tr>
<td>4</td>
<td>NUMBER OF BRANCHES</td>
<td>0.9987</td>
<td>0.9975</td>
<td>0.08</td>
<td>99.75</td>
<td>1.0229</td>
<td>1.6363</td>
</tr>
<tr>
<td>5</td>
<td>UNDEVELOPED OVULES</td>
<td>0.9993</td>
<td>0.9986</td>
<td>0.11</td>
<td>99.86</td>
<td>0.8590</td>
<td>3.0901</td>
</tr>
<tr>
<td>6</td>
<td>HEIGHT</td>
<td>0.9998</td>
<td>0.9995</td>
<td>0.09</td>
<td>99.95</td>
<td>0.5630</td>
<td>6.3123</td>
</tr>
<tr>
<td>7</td>
<td>NUMBER OF SEEDS</td>
<td>0.9998</td>
<td>0.9996</td>
<td>0.01</td>
<td>99.96</td>
<td>0.6693</td>
<td>0.1224</td>
</tr>
</tbody>
</table>
### TABLE 10

Stepwise Multiple Regression of Different Characters with Seed Yield
(Non-seed Dry Matter Wt. not included)

<table>
<thead>
<tr>
<th>No.</th>
<th>DEPENDENT VARIABLE</th>
<th>r</th>
<th>r²</th>
<th>% Increase in RSQ</th>
<th>Cumulative %</th>
<th>Std. Error of Estimate</th>
<th>F Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UNTHRESHED WEIGHT</td>
<td>0.9987</td>
<td>0.9974</td>
<td>99.74</td>
<td>99.74</td>
<td>0.8151</td>
<td>3126.10</td>
</tr>
<tr>
<td>2</td>
<td>NUMBER OF BRANCHES</td>
<td>0.9995</td>
<td>0.9990</td>
<td>0.16</td>
<td>99.90</td>
<td>0.5525</td>
<td>10.41</td>
</tr>
<tr>
<td>3</td>
<td>NUMBER OF PODS</td>
<td>0.9996</td>
<td>0.9991</td>
<td>0.01</td>
<td>99.91</td>
<td>0.5575</td>
<td>0.88</td>
</tr>
<tr>
<td>4</td>
<td>HEIGHT</td>
<td>0.9997</td>
<td>0.9993</td>
<td>0.02</td>
<td>99.93</td>
<td>0.5528</td>
<td>1.82</td>
</tr>
<tr>
<td>5</td>
<td>UNDEVELOPED OVULES</td>
<td>0.9997</td>
<td>0.9994</td>
<td>0.01</td>
<td>99.94</td>
<td>0.5550</td>
<td>0.44</td>
</tr>
<tr>
<td>6</td>
<td>DAYS FROM FLOWERING TO MATURITY</td>
<td>0.9998</td>
<td>0.9995</td>
<td>0.01</td>
<td>99.95</td>
<td>0.5744</td>
<td>0.74</td>
</tr>
<tr>
<td>7</td>
<td>NUMBER OF SEEDS</td>
<td>0.9998</td>
<td>0.9995</td>
<td>0.00</td>
<td>99.95</td>
<td>0.7001</td>
<td>0.02</td>
</tr>
</tbody>
</table>
correlation coefficient up to 0.9977. These two characters accounted for 99.53% of the variability in yield. The rest of the characters such as Days from flowering to maturity, Number of branches and Undeveloped ovules, and Plant height also improved the correlation coefficient to 0.9998 and accounted for the variability in yield up to 99.95%. When the next character, i.e., Number of seeds was included, there was no increase in their value, the cumulative percentage increased only by 0.01%, and the standard error of the estimate increased instead of decreasing farther. It was clear from this table that selection based on Non-seed dry matter weight and Number of pods should give promising results.

Equations for predicting seed yield based on the stepwise multiple regression analysis were formulated and have been given on page 55. The correlation coefficient between Unthreshed weight and Seed yield was 0.999 and between Non-seed dry matter weight and Seed yield was 0.992. Since Unthreshed weight gave the highest correlation, it was necessary to evaluate the order of importance of other characters having considerable influence on seed yield along with Unthreshed weight. This was accomplished by stepwise multiple regression analysis reported (Table 10), which revealed that Unthreshed weight alone accounted for 99.74% of the variability in Seed yield. Unthreshed weight and Number of branches together improved the $r$ value to 0.9995 and accounted for 99.90% of the variability in seed yield. It was further noted that the standard error of estimate was lowest at this point and thereafter it started to increase. This was an indication that no appreciable gain in seed yield could be made by considering other characters such as Number of pods,
Equations for predicting Seed Yield (Unthreshed weight not included);

\[ Y = -0.598 + 1.472 \, D_m \]
\[ Y = -2.032 + 0.919 \, D_m + 0.157 \, P \]
\[ Y = -7.390 + 0.578 \, D_m + 0.217 \, P + 0.084 \, D \]
\[ Y = -6.798 + 0.774 \, D_m + 0.177 \, P + 0.107 \, D -0.318 \, Br \]
\[ Y = -8.277 + 0.498 \, D_m + 0.167 \, P +0.166 \, D -0.439 \, Br + 0.114 \, ov \]
\[ Y = -28.886 - 0.232 \, D_m + 0.137 \, P + 0.466 \, D \]
\[ -0.850 \, Br + 0.123 \, ov + 0.416 \, Ht \]
\[ Y = -32.223 - 0.253 \, D_m + 0.154 \, P + 0.506 \, D \]
\[ -1.012 \, Br + 0.106 \, ov + 0.510 \, Ht -0.016 \, S \]

Equations for predicting Seed Yield (Non-seed dry matter weight not considered but instead Unthreshed weight considered). All symbols are the same as in previous equations, except \( u \) which stands for Unthreshed weight:

\[ Y = -0.410 + 0.599 \, u \]
\[ Y = 0.804 + 0.624 \, u - 0.237 \, Br \]
\[ Y = 0.094 + 0.568 \, u - 0.156 \, Br + 0.033 \, P \]
\[ Y = 0.489 +0.549 \, u - 0.141 \, Br + 0.062 \, P - 0.053 \, Ht \]
\[ Y = 1.078 + 0.529 \, u - 0.147 \, Br + 0.065 \, P - 0.074 \, Ht + 0.028 \, ov \]
\[ Y = -14.021 + 0.211 \, u - 0.533 \, Br + 0.105 \, P + 0.170 \, Ht + 0.078 \, ov \]
\[ + 0.238 \, D \]
\[ Y = -16.049 + 0.194 \, u - 0.619 \, Br + 0.115 \, P + 0.219 \, Ht + 0.074 \, ov \]
\[ + 0.264 \, D - 0.007 \, S \]

\( Y \) = Predicted seed yield
\( D_m \) = Non-seed dry matter weight
\( P \) = Number of pods
\( D \) = Days from flowering to maturity
\( Br \) = Number of branches
\( ov \) = Number of undeveloped ovules
\( Ht \) = Plant height
\( S \) = Number of seeds
Plant height, Undeveloped ovules, Days from flowering to maturity, and Number of seeds per plant. Equations for predicting seed yield when Unthreshed weight was considered along with other characters (excluding Non-seed dry matter weight) have been given on page 55 on the basis of stepwise multiple regression analysis.

D. Transgressive Segregation

The F₂ plants of Aoda x Kent and their parents were evaluated on the Number of days from the date of planting to the appearance of the first flower in 1972 (Fig. 14). Flowering of the male parent (Kent) started on July 23 and continued for 11 days, through August 2. During the first four days, 87% of the plants flowered and 13% flowered during the next seven days. The greatest number of plants (32 plants) flowered on July 25.

Flowering of the female parent (Aoda) started on August 3 and continued for six days, through August 8. During the first four days, 90% of the plants flowered and the remaining 10% flowered within the next two days. The greatest number of plants (32 plants) flowered on August 4.

The F₂ plants started flowering as early as July 17 and flowering continued for 40 days, through August 25. The greatest number of plants that flowered during a given day was 11. This occurred on three different dates, i.e., July 23, July 25, and August 7. There was no distinct peak of flowering time. Forty-eight percent of the plants flowered during the first 20 days and 52% flowered during the last 20 days. These data revealed that in the F₂ population, transgressive segregation occurred in this character. Veatch (39) also reported
Fig. 14. Relative performance of F2, and male (Kent) and female (Aoda) parents in Time of flowering.
transgressive segregation in days from planting to flowering, seed yield, seed number, and plant height.

The F2 generation of Aoda x Kent was also studied for pubescence color. The germination of the F2 seed was poor. Out of 273 seeds, only 165 seedlings emerged. The germination percentage of F2 seed was 60.4. One hundred and thirty plants had tawny pubescence and 35 had gray pubescence color. It was inferred that pubescence color was governed by a single gene with tawny pubescence (T) dominant to gray (t). These results are in agreement with Woodworth (44).
DISCUSSION

A high seed yield efficiency (SYE) ratio indicates that a higher proportion of the total weight of the plant is constituted by the seed weight. There was a marked variation in SYE among the varieties within a maturity group and among different maturity groups (Tables 3, 4). Wayne was found to be the most efficient variety with SYE of 1.52. Cayuga ranked second with SYE of 1.51. Aoda and Giant Green were the least efficient varieties and the SYE for these varieties was 1.28. This suggests that out of the total energy required in producing a Wayne plant, more is utilized in the production of seed. Aoda and Giant Green utilized more energy in the production of non-seed dry matter weight and consequently produced less seed weight. It was found that the highest yielding variety was Kent, which produced 59.0 grams of seed and 40.2 grams of non-seed dry matter. The SYE of this variety was 1.42. In contrast, Cayuga produced only 14.1 grams of seed and 9.3 grams of non-seed dry matter, but the SYE was very high (1.51). These data suggest that the high yielding varieties under cultivation today may not be the most efficient varieties from the point of view of energy utilization. The two most efficient varieties, Wayne and Cayuga, ranked second and ninth, respectively, in the production of seed and non-seed dry matter weight.

Another approach to study the extent of variability in SYE was the analysis of regressions of seed yield over dry matter weight.
This analysis revealed that a great deal of variability existed among the ten varieties investigated. Variability was observed within a maturity group as well as among different maturity groups (Tables 5,6). Hakote \( (y = 2.503 X -13.413) \) was the most efficient variety in producing seed yield per unit of non-seed dry matter weight, and Henry \( (y = 1.113 X +4.229) \) was the least efficient. Though the difference in the SYE between Hakote and Henry was significant (Table 4), these were not the most and least efficient varieties as far as SYE, as indicated by the ratio of seed yield to non-seed dry matter weight was concerned.

These differences in the two tests are due to the fact that Student's t test was not appropriate for testing significance between the ratios, because the ratios were not normally distributed. Secondly, two mathematically different parameters were being tested in the cases of ratios and regressions. In the ratio \( \frac{y}{x} = \tan \alpha \) the average angle from the origin is being tested, whereas in the analysis of regression coefficients by Chow's test, slope and intercept, together, are being tested. The latter is, therefore, a more appropriate test. However, both tests reveal that variability in SYE exists among the varieties.

Schultz and Brim (33), utilizing regression coefficient analysis, reported that certain varieties become more efficient in a competitive situation than in pure stands.

**Hybrid Vigor**

One cross of Aoda x Kent was studied in one plant of the F\(_1\) generation as to seed yield efficiency and other agronomic characters. Some characters had marked hybrid vigor, whereas others did not (Table 7). In agronomic investigations, yield is of major interest. To secure a
high yield per unit area of soil, there must be a good yield per plant and proper distribution of the plants over the area. Yield (weight) of seed produced per plant, has been used as one of the principal criteria to evaluate hybrid vigor in crop plants. The F₁ plant produced 50%, 76%, and 55.8% more Seed yield, Non-seed dry matter weight, and Unthreshed weight, respectively, than the high yielding parent. Wentz and Steward (43) reported that F₁ plants had marked hybrid vigor of seed yield and that the percentage increase of hybrids over parents ranged from 59.58 to 394.37. According to Veatch (39) seed yield is one of the best criteria to evaluate hybrid vigor, and he also observed considerable hybrid vigor as expressed by unthreshed weight in most crosses. Weiss et al. (42) found that only nine out of seventeen crosses yielded more than their high yielding parent under field conditions. They reported the average increase in yield above that of the high yielding parent was 32% in the greenhouse and 14% in the field. Kalton (21) also compared four F₁'s with their respective parents for two years and he reported hybrid vigor in all four crosses in one year and in two crosses in the other year. Leffel and Weiss (23) studied the superiority of F₁ over high parent in 45 F₁'s and found only 14 F₁'s with a significant hybrid vigor of seed yield. Brim and Cockerham (7) examined F₁ plants from two crosses in drilled sowings at two locations over two years and found that the performance of F₁ was considerably greater than that of the high yielding parent as to seed yield and unthreshed weight in one population and in yield only in the other.

The increase in yield in F₁ of this study was, however, not due to increased SYE of the F₁ plant. In F₁ SYE decreased 6.2% and 14.7% over
the parental average and high parent, respectively. According to Veatch (39) eight out of sixteen crosses had a higher straw-grain ratio than the parental average while only two were higher than the high parent. The height of F1 plant was 10.3% more than the taller parent. Similar results have been reported by Wentz and Stewart (43). Kalton (21), however, reported that F1's varied in height from intermediate between the two parents to taller than the tall parent. Leffel and Weiss (23) also found that only 10 F1's out of 45 F1's had hybrid vigor of height. Brim and Cockerham (7) reported that ten F1 plants were taller than the tall parent in one population but not in the second population.

The soybean produces from one to four seeds per pod. If production of seed is to be high, a plant must obviously produce either a large number of pods or a large proportion of three- and four-seeded pods. The F1 plant produced 64.7% more pods than the high parent. It was, however, observed that the female parent was a predominant producer of two-ovuled pods and the male parent produced more of the three- or-more-ovuled pods. In the case of the F1, the tendency was toward producing two-ovuled pods. The F1 plant produced 139.6% more two-ovuled pods than the high parent. The total number of seeds produced by the F1, was 20.8% more than the high parent but the number of seeds per pod did not increase either over the parental average or the high parent. Veatch (39) also reported similar results.

Other things being equal, the yield of a plant will be determined by the average seed size; that is, the higher the average seed size, the higher the yield of the plant. Seed weight per 100 seeds was used
as an indication of seed size. The F₁ seed size decreased 6.7% and 25.7% under the parental average and the high parent, respectively.

Wentz and Stewart (43), Veatch (39), and Woodworth (48) evaluated many crosses in the F₁ generation and observed an increase in seed size in very few instances. The number of undeveloped ovules increased 127.2% and 69.6% over the parental average and the high parent, respectively. This suggests that highly productive plants also produce more undeveloped ovules.

Height from ground to first pod is important because the height of the pod on the main stem is associated with the corresponding reduction expected in harvesting loss. Podding height in the F₁ was 72.7% and 35.7% more than the parental average and the high parent, respectively. It was, however, noted that the F₁ was considerably taller than the tall parent. Carter and Hartwig (9), Greer, and Anderson (12), and Arora (2) reported that when height was reduced, pods formed closer to the ground.

Number of branches in the F₁ increased 6.3% over the parental average, but when compared to the high parent, a reduction of 5.6% was observed. This suggests that partial dominance of high number but no appreciable hybrid vigor was expressed in number of branches per plant. Number of branches per plant has not been shown thus far to be an important yield component.

The F₁ increased 3.5% in the number of days from flowering to maturity over the parental average, but it was 3.6% less when compared with the high parent. This is an indication that lateness is partially dominant but without hybrid vigor in this cross. Woodworth (45)
reported that late maturity was dominant in the progeny of a plant that segregated tall late and short early plants.

**Phenotypic Correlations**

Phenotypic correlations between yield and yield components are important to any plant breeder. The importance of correlations among the yield components also cannot be over emphasized. The extent of the association of various plant characters with yield has been a subject of investigation for a long time. The correlations among various characters reported by different workers are highly variable. However, the following are consistent in sign and appreciable in magnitude. Height and earliness are negatively correlated. The correlation between height and resistance to lodging is also negative. Early flowering and early maturity are positively correlated. Early flowering is also positively correlated with the length of fruiting period. Woodworth (48), as early as 1933, observed that number of seeds, low percentage of aborted seeds, and high unit seed weight were highly associated with yield. He concluded that varieties with a low percentage of abortive seed and large seed tend to produce high yields. The results reported in this study are not in complete agreement with Woodworth (48). In this study, it was observed that while the Number of seeds \( r = 0.939 \) and the Number of undeveloped ovules \( r = 0.970 \) were highly correlated with Seed yield, Seed size \( r = -0.035 \) was not associated with yield. These data indicate that a variety may produce a large seed size, but it may produce fewer seeds and as a consequence total seed yield will be low. It was found that Aoda, which produced 32.1 grams Seed size (weight per 100 seeds), gave a Seed yield of 27.2
gm./plant. On the other hand, Kent produced 59.0 grams of seed per plant but the weight of 100 seeds was only 18.4 grams. It is suggested that Seed size is not an indication of high Seed yield for any variety because it may produce fewer or more seeds per plant. Howell (17) stated that weight per 100 seeds did not have any effect on yield per acre. It was further observed during this investigation that as a variety became more productive, it tended to produce more undeveloped ovules.

Plant height \( (r = 0.894) \) and Number of pods \( (r = 0.983) \) were found to be highly associated with Seed yield. These results are in agreement with Weatherspoon and Wentz (40) and Ma (24), who found also a high association between Number of seeds per pod and Yield. The correlation coefficient between Number of seeds per pod and Seed Yield obtained in this study was 0.428. The reason for this low \( r \) value lies in the classification of one-, two-, and three- or-more ovuled pods in this case. When a pod contained two seeds and one undeveloped ovule, it was counted as a three-ovuled pod. In other words, immature ovules were counted while classifying pods as one-, two-, and three- or-more-ovuled pods. However, Howell (17) reported that isogenic lines developed by Hartwig, differing only in number of seeds per pod (1.5 and 2.5) or in size of seeds (8.5 grams per 100 seeds versus 13.5 grams per 100 seeds) did not differ significantly in yield. A high association \( (r = 0.812) \) between Days from flowering to maturity and Seed yield was observed. Similar results have been obtained by Weber and Moorthy (41) and Yoshino (49).
The extent of association of Unthreshed weight, Non-seed dry matter weight, Podding height and SYE with Seed yield were also included in these investigations. It was found that Unthreshed weight \((r = 0.999)\) and Non-seed dry matter weight \((r = 0.992)\) were highly associated with Seed yield but Podding height \((r = -0.152)\) was not associated with Seed yield. These data revealed that Unthreshed weight or Non-seed dry matter weight could be used in the selection program for high yields. It was found that yield attributes, which were significantly associated with yield, also were appreciably correlated among themselves (Table 8). Also, few cases were observed where the extent of association was not statistically significant.

The association between Days from flowering to maturity and Height \((r = 0.502)\) was not significant. Plant height and Number of branches also did not have a significant association \((r = 0.518)\). Number of branches did not yield significant correlation \((r = 0.472)\) with Number of seeds. It was, however, observed that \(r\) values obtained for the association of these characters were not very far from the value required to be significant at the 5% level \((0.549)\). However, the studies conducted on yield components have been contradictory.

According to Howell (17) unit seed weight and number of seeds per pod did not affect yield significantly. He further observed that even the removal of some of the leaves or pods had little or no effect on yield unless the removal included a major portion of the total. Thus, unit seed weight, number of pods (unless greatly reduced), or seeds per pod do not seem to be important components of yield.
Phenotypic correlations should indicate the relative importance of several yield attributes in producing yield and the attribute or attributes upon which most attention should be given. Johnson et al. (19) observed that selection based on maturity, seed weight, or resistance to lodging was approximately 50% as effective in improving yield as selection based on yield alone. However, Hanson and Weber (15) reported that number of pods, lodging, plant height, and maturity are important visual concepts of yield. Anand and Torrie (1), and Kwon and Torrie (22) observed that selection based on tallness, late maturity, and susceptibility to lodging was 50% as efficient as selection based on yield alone. These results indicate that a breeder may advance lines in early generations based on the performance of traits other than yield itself especially when it is known that heritability of yield is low.

When Unthreshed weight and Non-seed dry matter weight were included in the same set along with other characters for stepwise multiple regression analysis, the correlation coefficient became unity after the selection of Unthreshed weight and Non-seed dry matter weight. This sheds no light on the importance of other yield attributes. Therefore, it was decided to compare Unthreshed weight and Non-seed dry matter with other characters independently in two separate sets of analyses (Tables 9 and 10).

These data suggested (Table 9) that Non-seed dry matter is an important character on which emphasis could be given when selecting for higher yield. This character alone was responsible for 98.38% variability in seed yield. The second important character in this set
was Number of pods. Together Non-seed dry matter weight and Number of pods were responsible for 99.53% variability in seed yield. The increase due to Number of pods was only 1.15%. It is suggested that Non-seed dry matter weight is by far the most important character for the purpose of selection.

The data in Table 10, however, revealed that Unthreshed weight was also very effective in accounting for the variability (99.74%) in seed yield. Unthreshed weight gave slightly better results than Non-seed dry matter weight. The second important character in this set was Number of branches which increased the effectiveness by only 0.16%. It is suggested that since Unthreshed weight gave better results than Non-seed dry matter weight and this parameter is also easier to record in the field, selection for higher yield should be based on Unthreshed weight.
SUMMARY AND CONCLUSIONS

The present investigation was undertaken at The Ohio State University Farm, Columbus, Ohio, during 1970 to 1972. The main objectives of the study were to investigate variation in Seed yield efficiency (SYE), defined as either a high ratio of mature seed yield to non-seed dry matter weight (above ground unthreshed weight of plant at maturity minus its seed yield) or a steep slope in the regression of seed yield over non-seed dry matter weight, in soybean varieties belonging to different maturity groups. The study of hybrid vigor, and phenotypic correlations of some important agronomic characters with seed yield was also included in these investigations.

Ten varieties of soybean differing in characters such as Maturity, Height, Seed coat color, Pubescence color, and Seed yield were studied.

There was considerable variability in SYE in these soybean varieties within the same maturity group and among different maturity groups. The variability in SYE ranged from 1.52 to 1.28. The F1 plant increased slightly in SYE over the low parent. However, SYE of the F1 plant was less as compared to the parental average or the high parent. It appears that in this case SYE factor are partially dominant. Regression analysis also revealed a significant amount of variability among different varieties as to SYE within maturity groups as well as among different maturity groups.

Some plant characters had considerable hybrid vigor, while others did not. Hybrid vigor was expressed in the form of Non-seed dry matter
weight, Seed yield, Unthreshed weight, Plant height, Two-ovuled pods, Total pods, Number of seeds, Undeveloped ovules, and Podding height. Seed yield efficiency, Three- or-more-ovuled pods, Number of seeds per pod, Number of branches and Seed size did not have appreciable hybrid vigor.

Non-seed dry matter weight and Unthreshed weight were highly associated with Seed yield. Other characters having a high association with Seed yield were: Days from flowering to maturity, Plant height, Number of branches, Pods, Seeds, and Undeveloped ovules. Some characters such as Seeds per pod, Seed size, Podding height and SYE were not associated with Seed yield. Generally, the characters which had high association with Seed yield also were highly associated among themselves.

Transgressive segregation occurred in F2 generation in the Number of days from seeding date to the appearance of the first flower.

A considerable amount of variability in SYE has been found in soybean varieties. It is hoped that further gains in soybean seed yield can be made by incorporating in breeding programs those varieties which are most efficient seed producers.

Hybrid vigor can be utilized for improving seed yield. Transgressive segregation occurs in the case of Days from planting to flowering. Desired segregates can be selected and advanced for further testing.

Selection based on Non-seed dry matter weight or Unthreshed weight should be helpful in improving soybean seed yield.
A P P E N D I X
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Hakote $Y = 2.503X - 13.413$
Kent $Y = 1.626X - 6.314$
Henry $Y = 1.113X + 4.229$

Fig. 15. Regressions of Seed yield over Non-seed dry matter weight in Hakote, Kent and Henry.
Fig. 16. Regressions of Seed Yield over Non-seed dry matter weight in Giant Green, Wayne, and Kura.
Fig. 17. Regressions of Seed Yield over Non-seed dry matter weight in Manchuria, Habaro, Cayuga and Aoda.

- Manchuria: $Y = 1.960X - 2.978$
- Habaro: $Y = 1.682X - 2.436$
- Cayuga: $Y = 1.629X - 1.022$
- Aoda: $Y = 1.455X - 2.840$
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