This dissertation has been microfilmed exactly as received

SANFORD, Lind Lee. COMPARATIVE EVALUATION OF CLONES AS TESTERS FOR YIELD, SPECIFIC GRAVITY AND TUBER APPEARANCE IN THE POTATO.

Iowa State University of Science and Technology
Ph.D., 1960
Agriculture, general

University Microfilms, Inc., Ann Arbor, Michigan
COMPARATIVE EVALUATION OF CLONES AS TESTERS FOR YIELD, SPECIFIC GRAVITY AND TUBER APPEARANCE IN THE POTATO

by

Lind Lee Sanford

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of The Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Major Subject: Horticulture

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

Head of Major Department

Signature was redacted for privacy.

Dean of Graduate College

Iowa State University Of Science and Technology Ames, Iowa

1960
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>REVIEW OF LITERATURE</td>
<td>3</td>
</tr>
<tr>
<td>Evaluation of Parental Material</td>
<td>3</td>
</tr>
<tr>
<td>Potatoes</td>
<td>3</td>
</tr>
<tr>
<td>Corn</td>
<td>4</td>
</tr>
<tr>
<td>Forage crops</td>
<td>6</td>
</tr>
<tr>
<td>Vegetable crops</td>
<td>8</td>
</tr>
<tr>
<td>Statistical Investigations of General and Specific Combining Ability</td>
<td>9</td>
</tr>
<tr>
<td>MATERIALS AND METHODS</td>
<td>13</td>
</tr>
<tr>
<td>DESIGN AND ANALYSIS OF THE EXPERIMENT</td>
<td>17</td>
</tr>
<tr>
<td>EXPERIMENTAL RESULTS</td>
<td>30</td>
</tr>
<tr>
<td>Yield</td>
<td>30</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>40</td>
</tr>
<tr>
<td>Tuber Appearance</td>
<td>43</td>
</tr>
<tr>
<td>Relationship between Testers and Lines</td>
<td>47</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>49</td>
</tr>
<tr>
<td>SUMMARY</td>
<td>56</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>58</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>62</td>
</tr>
</tbody>
</table>
INTRODUCTION

Cytological and genetic evidence indicates that *Solanum tuberosum* may be an old species. Since 1850, a great deal of effort has been directed toward selecting superior varieties. Beginning with the variety Garnet Chili, released in 1857 by Rev. Goodrich of Utica, New York, breeding procedure has been based largely upon single plant selection among sexually propagated progenies. Although selection of this type has been the major breeding method for the past 100 years, it has been observed that the potato is a crop difficult to improve through standard breeding methods. This difficulty is in part due to its tetraploid inheritance. Furthermore, it is highly probable that over a period of time some of the chromosomes have become differentiated to the extent that both allopolyploid and autopolyploid behavior exist. Pollen sterility barriers have been encountered, particularly in early generations of inbreeding. This has been accentuated by a tendency toward an inverse relationship between fertility and yield. Recently it has been noted that recombinations of inbred lines infrequently result in heterosis for yield. This is in sharp contrast to the relatively consistent appearance of hybrid vigor found within many vegetable crops. All of these factors combine to restrict efficiency of breeding and selection methods. It is only recently that new breeding methods have been proposed to increase the effectiveness of potato improvement. Many of these are adaptations of those used to improve corn inbreds or varieties. In testing any of these techniques, consideration should be given to the
vegetative propagation of the potato, to its unit land requirement, and to its genetic complex.

This study was undertaken as part of a program to develop recurrent selection as a breeding method for potato improvement. Through evaluation of general and specific combining ability for total yield, specific gravity, and general tuber appearance, it was hoped that efficient testers for these characters could be found. Estimates of general and specific combining ability also were to be related eventually to the type of recurrent selection most efficient in improving each character.
REVIEW OF LITERATURE

Evaluation of Parental Material

Potatoes

The importance of superior parental material in a potato breeding program was stated by Krantz and Hutchins (28, p. 4) as follows:

The problem of potato improvement is essentially one of developing individuals for breeding purposes. The usefulness of these individuals will not depend upon their own performance, but upon their breeding value as ascertained by a study of their progeny; and upon their ability when crossed, to produce other individuals of economic value. The physical limitations on the number of lines that can be grown makes it obligatory to practice some type of selection so desirable germ plasm can be sorted out and saved and the undesirable discarded.

In a study of 47 F₁ crosses, Krantz and Hutchins (28) found the regression of parental yields on F₁ yields to be 0.5564 ± 0.1079. It also appeared that selection within self-fertilized lines was a practical method of securing improved parental materials.

Gowen (11) indicated that tests of selfed progeny gave an evaluation of parental genotypes more accurate than those obtained through progenies from crosses of phenotypically superior heterozygous plants. Inbred selections with combining ability superior and inferior to that of their parents were tested. Significant differences in specific combining ability frequently were found between closely related inbreds. A
greater dispersion of combining abilities occurred among self-pollinated lines than among heterozygous lines.

Rieman et al. (39) proposed potato improvement through parental line breeding. The investigation of breeding methods for their efficiency in producing parental lines of high combining ability was felt to be desirable. In particular, the authors cited a need for finding the degree of homozygosity required in lines superior in disease resistance, tuber type, and total solids.

Corn

Hayes and Johnson (16), Jorgenson and Brewbaker (22), Nilsson-Leissner (37), and Kiesselbach (26) compared the productivity of pure line parents with their hybrid offspring and found a positive relationship. In contrast, Richey and Mayer (38), and Jenkins (19) reported data suggesting little or no relationship between the productivity of pure line parents and their hybrid offspring.

The use of the inbred-variety cross as a means of isolating higher yielding lines was first proposed by Davis (5). Jenkins and Brunson (20) suggested that crosses with a commercial variety could be used as a rapid method of preliminary tests of new inbred lines. On the basis of performance in such crosses, it was felt that 50 percent of the lines could be discarded without a serious loss of valuable material. Johnson and Hayes (21) compared the performance of 11 sweet corn lines crossed in all possible combinations with the performance of these lines in top-cross tests. Inbreds that showed low
combining ability in top-cross tests were usually low in average single cross performance. Similar results were observed for high combining lines.

Federer and Sprague (9) analyzed a series of 11 top-cross tests containing two or more testers. The results suggested that, for a fixed number of plots, the greatest gain in combining ability would be expected by increasing the number of testers. An increase in the number of lines, and particularly in the number of replications, resulted in a progressive decline in breeding efficiency. It was suggested that the choice of a tester for a given set of lines should be determined by the future use of such lines. If maximum general combining ability were desired, the use of more than one tester would be recommended. Green (13) compared a high-yielding double cross with a low-yielding, open-pollinated line for use as testers of segregating F₂ progenies. The results generally revealed no differences between the two testers, although some interaction with F₂ segregates was observed. It was suggested that genes affecting specific combining ability were important in the gametic samples of the tester parents. The wide range of top-cross yields, using the double cross tester, appeared to be an indication of this sampling importance. The use of related and unrelated single crosses as tester parents in evaluating a group of selected F₂ plants was studied by Keller (25a). The difference between the testers was revealed by dissimilar ranking of F₂ plants. It was suggested that the different rankings were due to differences in specific combining ability between the testers and the F₂.
plants. Results obtained by Grogan and Zuber (14) indicated that a tester closely related to the inbred lines under study should not be used when general combining ability information is desired. Matzinger (32) crossed eight inbred lines to three types of testers. These testers consisted of: (1) the eight inbred lines, (2) two double crosses, and (3) the four single crosses comprising each double cross. The three types of testers gave similar means and ranges for general combining ability in test-cross progenies. Each tester also gave a consistent ranking.

Lonnquist and Rumbough (31) found that lines selected for specific combining ability represented a random sample with respect to general combining ability. This was observed in a comparison of selected lines with unselected material from the same original source. These data seemed to support the accepted procedure of testing new lines for general combining ability before determining specific combining ability. Hull (18) proposed the use of a single homozygous line as a tester in selecting for specific combining ability. This method seemed to be relatively efficient in selecting lines for superior hybrid combinations.

Forage crops

The term "polycross" was first proposed by Tysdal et al. (45) to designate "the progeny from seed of a line that was subject to outcrossing with the other selected lines growing in the same nursery". The same procedure had been suggested earlier by Frandsen (10). Bolton (2) concluded that alfalfa clones of low and high combining ability
performed with equal efficiency when used as testers. The results indicated that the use of testers could be helpful in determining combining ability in a large population of plants. Tysdal and Grundall (44) found that tested clones were ranked similarly by polycross progenies, top-cross progenies, and the average performance of single crosses having a common parent. The performance of parental clones was generally found to be indicative of the performance of their progenies, particularly for insect and disease resistance. Davis and Panton (6) compared single crosses, $S_1$ progenies, and two types of polycrosses for testing clones of high and low phenotypic performance. Variances for mature plant yield, components of yield, and seedling height were statistically significant when computed from means of $S_1$ and single cross progenies. No significance was found when polycross progeny means were analyzed. The clones characterized by high phenotypic performance generally produced superior yield in progenies.

Hanson et al. (15) used a polycross progeny test in orchard grass to relate the combining ability of 18 parental lines to that of 52 of their selfed progenies. The general combining ability of most of the inbred lines was not materially different from that of their parental clones. Results indicated, however, that lines with general combining ability higher and lower than that of original clones could be selected. Kalton et al. (24) found that clonal performance was of little value in predicting combining ability. Single cross, polycross, and top-cross progenies generally predicted combining ability in a similar manner.

Dhawan (7) found in timothy that the polycross progeny gave a
reliable estimate of general combining ability for plant vigor and re-
growth. Both polycross and \( S_1 \) progenies were found to be efficient in
predicting general combining ability for leafiness and stem rust
resistance.

Knowles (27), in studies of open-pollinated progenies from
selected brome grass plants, found a relationship between the open-
pollinated progenies and test-cross progenies with respect to forage
production. It was concluded that a test of open-pollinated progenies
of selected plants would be useful in obtaining superior combining
ability for this character. Timothy \textit{et al.} (43) showed that clones dif­
f ered in general combining ability for forage yield, seed yield, and
leaf spot reactions. Specific combining ability was significant for
plant height, but general combining ability effects could not be shown.
There was fair agreement of clone rankings between polycross progeny
performance and the average single cross performance. Nielson and
Kalton (36) studied the effect of one generation of inbreeding on com­
bining ability and found it to be negligible.

\textbf{Vegetable crops}

Larson and Currence (29) found little relationship between variety
yields and yields of their \( F_1 \) hybrids in tomatoes. In a later study,
\textit{Currence et al.} (4) found an agreement between variety yields and
general combining ability for yield. It was suggested that varieties
productive within an adapted area would probably produce superior
yielding hybrids in this area. Moore and Currence (35) attempted to
predict general combining ability by crossing each of 25 tomato varieties and two selections with two different $F_1$ hybrids. The resulting three-way crosses were then grown in a replicated trial along with the 27 parents. Eight strains, showing a range of combining ability, were selected and grown with all possible hybrid combinations, including reciprocals. The results indicated that the mean performance of a variety in a series of crosses provided the best measure of general combining ability. The three-way cross did not appear to be superior to varietal performance as an indication of combining ability. Horner and Lana (17), working with fruit size, early U.S. No. 1 yield, and yield of all grades, found that the best general combiners could be predicted from parental values with reasonable accuracy.

In progeny tests of asparagus plants, Currence (3) found that parents selected for higher phenotypic performance for seedling size and yield tended to produce superior progenies. The desirability of progeny tests was demonstrated by a 50 percent yield increase of two superior lines in comparison with the mean of all lines.

Statistical Investigations of General and Specific Combining Ability

Combining ability was divided into two types by Sprague and Tatum (42). General combining ability was defined as the average performance of a line in a number of hybrid combinations. Specific combining ability was meant to describe the extent to which a cross deviated from expectation on the basis of general combining ability.
General combining ability values are considered to be due predominantly to additive gene action, whereas specific effects are a result of such non-additive gene responses as dominance, epistasis, and other types of gene interaction.

Corn data presented by Sprague and Tatum (42) indicated that general combining ability was more important than specific combining ability in single crosses made up of untested material. However, in trials involving previously tested lines, specific combining ability appeared to be relatively important. The results of Federer and Sprague (9) agreed with those of Sprague and Tatum. Similar conclusions were reported by Kalton and Leffel (23) in a study of orchard grass clones. However, Matzinger et al. (34) analyzed diallel crosses of ten corn plants selected at random from the open-pollinated variety, Low Ear. The results showed little variance due to general combining ability. Considerable variance was found for specific combining ability. It was concluded that the estimate of general combining ability was of little use as a criterion for selection in this population. The use of specific combining ability was regarded as more valuable.

Models for obtaining estimates of variance components for general and specific combining ability and their interactions with years were presented by Rojas (40). Rojas and Sprague (41) tested these models by analyzing single crosses in corn, replicated by locations and years. Variance components for specific combining ability showed consistently greater interactions with environment than did those variance components for general combining ability. This
indicated the presence of genotypic-environmental interaction in the estimate of specific combining ability variance. Interaction with environment appeared to decrease as the heterogeneity of the material increased. Matzinger (33) found additive variance to be negligible when estimated from a combined analysis of experiments run over locations and years. Additive variance interacted significantly with years, but not with locations. Dominance variance showed little interaction with either years or locations. Ballesteros (1) studied top-cross progenies of S2 and S3 lines of White Flint for two seasons in three locations. There was no significant interaction between top-crosses and locations and among top-crosses, locations, and seasons. It was concluded that a performance test to determine general combining ability, conducted at one location, would effectively eliminate lines for subsequent specific combining ability tests. In testing the same lines for specific combining ability with a selected single cross, however, a highly significant interaction between locations and hybrids was obtained. Thus, it was concluded that specific crosses must be tested at several locations and in several years to obtain sufficient information on their yielding potential.

Green (12) investigated the inheritance of combining ability in the F2 generation of three single crosses in corn. These crosses represented combinations of high x high, high x low, and low x low combining inbreds. The frequency of high combining F2 segregates in the progeny of the high x high cross was found to be higher than that
in the other two crosses. This difference indicates that combining ability is an inherited characteristic. Lonnquist (30) demonstrated that combining ability, for a group of lines or families, remains relatively stable from $S_1$ through subsequent selfed generations.
MATERIALS AND METHODS

In 1956, six clones were selected for use as tester parents. These included: B962-32, ND457-1, B3131-8, TL1859, X96-56, and Katahdin. Each of the clones had demonstrated superiority in pollen fertility. Each clone also had shown superior combining ability for one or more of the characteristics, yield, specific gravity, and tuber type. This performance was observed in several varietal breeding programs. Pollen from each of the six tester parents was crossed with 45 phenotypically distinct clones. These clones included 34 lines from the breeding programs of Iowa, North Dakota, Nebraska, and the United States Department of Agriculture, as well as six released varieties and five species hybrids. The 45 lines were chosen at random from available material. The total number of possible crosses among testers and lines would be 270, but due to various failures, only 190 were successful. The crosses made are presented in Table 1. Samples of true seed of each cross were sent to Ithaca, New York. Progenies were further subdivided for trials at Ithaca and Riverhead, New York.

In 1957, seedling tubers of each of the crosses were planted for increase. One to three tubers were harvested from each seedling plant and bulked as family lines. The number of tubers harvested from each plant was determined by the number of such plants in the family line. Each tuber in a bulked line was cut once to obtain a sample of 66 seed pieces. If the number of tubers was insufficient to obtain
Table 1. Crosses obtained between six testers and 45 clonal lines of potatoes<sup>a</sup>

<table>
<thead>
<tr>
<th>Line No.</th>
<th>Pedigree No.</th>
<th>Katahdin</th>
<th>TL1859</th>
<th>B962-32</th>
<th>ND457-1</th>
<th>X96-56</th>
<th>B3131-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>I957-1</td>
<td></td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>II015-2</td>
<td>X</td>
<td>(X)</td>
<td>(X)</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>II077-16</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>II077W28-5</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>II114-2</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Early Gem</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td>(X)</td>
</tr>
<tr>
<td>7</td>
<td>B1396-N2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>B2938-22</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>B2903-17</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>II188-2</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td>(X)</td>
</tr>
<tr>
<td>11</td>
<td>B922-3</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td>(X)</td>
</tr>
<tr>
<td>12</td>
<td>B922-6</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td>(X)</td>
<td>(X)</td>
</tr>
<tr>
<td>13</td>
<td>B2834-3</td>
<td>(X)</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td></td>
<td>(X)</td>
</tr>
<tr>
<td>14</td>
<td>B3014-10</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>B3097-16</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>B3131-N2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>B3428-31</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>B3428-41</td>
<td>X</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>B3556-12</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td>(X)</td>
<td>(X)</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>PI194665</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>TL1859</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>ND457-1</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>OB2905-1</td>
<td>(X)</td>
<td>(X)</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>PI214372-1</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>25</td>
<td>PI214371-2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>PI214372-2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>P51.1-53-15</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>II049-3</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>II092-2</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>II165-14</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>II1216-1R</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>B605-10</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>B2368-4</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>B3131-8</td>
<td>X</td>
<td>(X)</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>B3556-1</td>
<td>X</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>X927-3</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>AC25953</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>N154-47-2</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>OB3596-1</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Earlain</td>
<td>X</td>
<td>(X)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Katahdin</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>Osage</td>
<td>(X)</td>
<td>(X)</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Red Kote</td>
<td>(X)</td>
<td>(X)</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>I1077-14</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>B24-58</td>
<td>(X)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup> X - Tester and line with no common parent or grandparent
(X) - Tester and line with at least one common parent or grandparent
66 pieces with one cut, a second cut was made. This procedure was used in an attempt to obtain a representative sample for each family. Care was taken in cutting to assure that each seed piece weighed approximately two ounces.

In 1958, the 190 bulked test-cross lines and ten commercial check varieties were planted in a rectangular lattice design at Clear Lake, Iowa; Riverhead, New York; and Ithaca, New York. Six replications were used at each location. Each plot consisted of ten hills spaced one foot apart. The stand at all locations was excellent; therefore, no statistical adjustment was deemed necessary. Data taken from each plot at Clear Lake, Iowa, included total weight, specific gravity, and a general tuber appearance rating. Only total weight measurements were recorded at the two New York locations.

Specific gravity of tubers was obtained by the water displacement method. The tubers were first weighed in air. The same sample was then weighed in water, using a special counter-balanced scale. Specific gravity was calculated from the formula

\[
\text{Specific gravity} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{Weight in water}}
\]

All tubers in a plot were used to determine specific gravity unless total weight exceeded 20 pounds. A maximum of 20 pounds was felt to be adequate for measuring this character.

The tuber appearance ratings were based upon an arbitrary numerical scale of one to eight. The figure eight represented the most desirable tuber appearance relative to existing varietal characteristics.
The least desirable tuber was designated by the number one. Four characteristics were used as a basis for the rating: (1) depth of eyes, (2) regularity of shape, (3) susceptibility to growth cracks, and (4) susceptibility to second growth. Such factors as susceptibility to scab, russet skin versus smooth skin, and skin color differences were disregarded. It should be emphasized, however, that these differences undoubtedly affect tuber appearance.
DESIGN AND ANALYSIS OF THE EXPERIMENT

The experimental design used for this experiment is an adaptation by Federer and Plaisted (8) of a triple rectangular lattice. The adaptation permits the comparison of \( v = 2k \) treatments in \( b = 2rk \) incomplete blocks of \( k \) treatments with \( 3q = r \) replicates. The structure is closely related to the structure of rectangular lattices in a way to be exemplified later. The basic plan, consisting of three replicates with different confounding, is repeated \( q \) times; therefore, the total of \( r \) equals \( 3q \) replicates. The experiment included 200 treatments. Ten treatments were assigned to each of 20 blocks in a replicate. A series of three arrangements was duplicated to give a total of six replicates.

The actual arrangement, apart from randomization, is given in Table 2. Treatments are designated by \( ijk \), where \( i \) equals one or two, and both \( j \) and \( k \) range from one to \( k \).

Treatments were randomly assigned field numbers from 1-200. These were then grouped into incomplete blocks according to the arrangements outlined in Table 2. The blocks were arranged at random in each replicate, and then each treatment was randomly assigned to the plots within incomplete blocks. The three arrangements were duplicated for replicates four, five, and six, but with different randomization. Thus, in the present design, \( q \) equals two. This experimental design completely confounds one degree of freedom (treatments 111 to 1kk versus treatments 211 to 2kk) with differences among incomplete blocks.
Table 2. Structure of the experiment

<table>
<thead>
<tr>
<th>Block No.</th>
<th>Replicate Type I</th>
<th>Replicate Type II</th>
<th>Replicate Type III</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>111</td>
<td>112</td>
<td>122</td>
</tr>
<tr>
<td>2</td>
<td>121</td>
<td>122</td>
<td>123</td>
</tr>
<tr>
<td>3</td>
<td>131</td>
<td>132</td>
<td>134</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>k</td>
<td>1k1</td>
<td>1k2</td>
<td>1k3</td>
</tr>
<tr>
<td>k+1</td>
<td>211</td>
<td>212</td>
<td>213</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>2k</td>
<td>2k1</td>
<td>2k2</td>
<td>2k3</td>
</tr>
</tbody>
</table>

Note: The table continues with similar entries for Type II and Type III replicates.
In order for the reader to be able to understand this design, the following description was abstracted from an unpublished paper of Federer and Plaisted (8):

The normal equations employed to compute totals for each effect are shown below. $Y_{ijg}$ is the total yield of the $i^{th}$ treatment of the $j^{th}$ type replicate and the $g^{th}$ block in that replicate. Sums over subscripts are represented by replacing the subscripts with dots; for example, $Y_{i..} = \sum_{jg} Y_{ijg}$.

1. $Y_{...} = \text{Grand total} = urv + v \sum_{j=1}^{r} \beta_j + r \sum_{i=1}^{r} \tau_i + k \sum_{j=1}^{r} \sum_{g=1}^{2k} \beta_{jg}$

2. $Y_{i..} = i^{th}$ treatment total $= r(u+\tau_i) + \sum \beta_j + \text{sum of block effects}$ for blocks in which $i^{th}$ treatment occurred;

3. $Y_{.j.} = j^{th}$ replicate total $= v(u+\beta_j) + \sum \tau_i + \sum \beta_{jg}$

4. $Y_{.jg} = jg^{th}$ incomplete block total $= k(u+\rho_j + \beta_{jg}) + \text{sum of treatment effects for treatments occurring in block } jg$;

where $u = \text{grand mean},$

$\tau_i = i^{th}$ treatment effect,

$\rho_j = j^{th}$ replicate effect,

$\beta_{jg} = jg^{th}$ incomplete block effect.

The above plus the following equations result in unique solutions for the $\mu$, $\tau_i$, $\rho_j$, and $\beta_{jg}$ effects:
\[
\sum_{i=1}^{2k^2} \tau_i = \sum_{j=1}^{r} \rho_j + \sum_{g=1}^{k} \beta_{jg} = 0 ;
\]
\[
\sum_{i=k^2+1}^{k^2} \tau_i = \sum_{g=k+1}^{k} \beta_{jg} = \frac{1}{r} \sum_{j=1}^{r} \sum_{g=k+1}^{k} \beta_{jg} ;
\]
\[
\sum_{i=k^2+1}^{2k^2} \tau_i = \sum_{g=k+1}^{k} \beta_{jg} = \frac{1}{r} \sum_{j=1}^{r} \sum_{g=k+1}^{k} \beta_{jg} .
\]

The solutions for the \( \beta_{jg} \) are

\[
\hat{\beta}_{jg} = \frac{1}{2qk^2} \left\{ 3kQ_{.jg} - \sum_{g=1}^{k} Q_{.jg} \right\} + \frac{1}{k(k+1)} \sum_{i=1}^{k^2} (\bar{y}_{i..} - \bar{y})
\]

for \( g = 1, 2, \ldots, k \), and

\[
\hat{\beta}_{jg} = \frac{1}{2qk^2} \left\{ 3kQ_{.jg} - \sum_{g=k+1}^{2k} Q_{.jg} \right\} + \frac{1}{k(k+1)} \sum_{i=k^2+1}^{2k^2} (\bar{y}_{i..} - \bar{y})
\]

for \( g = k+1, k+2, \ldots, 2k \). If \( q \) equals one, the value for \( Q_{.jg} \) equals the total for the \( g^{th} \) block in the \( j^{th} \) replicate minus the mean yield over all replicates of the treatments appearing in block \( g \) of the \( j^{th} \) replicate. If \( q \) is greater than one, \( Q_{.jg} \) is equal to the sum of the block totals, which contain the same treatments, minus \( q \) times the overall mean yield of the treatments occurring together in the blocks.

The adjusted variety means are \( \hat{u} + \hat{\gamma}_i = \bar{y} + \hat{\tau}_i \), and the \( \hat{\tau}_i \) are obtained from the normal equations for the treatments. This formula expresses the variety mean adjusted for intrablock information only.
The analysis of variance for this design is presented in Table 3.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Sum of squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>$2rk^2-1$</td>
<td>usual method</td>
</tr>
<tr>
<td>Replicates</td>
<td>$r-1$</td>
<td>$\sum_{j=1}^{r} \left( Y_{ij}^2 - \frac{Y^2}{2rk^2} \right)$</td>
</tr>
<tr>
<td>A = Treatments 1-100 versus 101-200</td>
<td>1</td>
<td>$\left[ \sum_{i=1}^{k} Y_{i.} - \frac{2k^2}{\sum_{i=k+1}^{2k} Y_{i.}} \right] \frac{1}{2rk^2}$</td>
</tr>
<tr>
<td>A x replicates</td>
<td>$r-1$</td>
<td>usual method</td>
</tr>
<tr>
<td>Treatments within groups (ignoring blocks)</td>
<td>$2k^2-2$</td>
<td>$\sum_{i=1}^{200} Y_{i.}^2 / r - \frac{Y^2}{rv}$</td>
</tr>
<tr>
<td>Incomplete blocks (eliminating treatments)</td>
<td>$6qk - 6q$</td>
<td></td>
</tr>
<tr>
<td>Component (a)</td>
<td>$6(q-1)(k-1)$</td>
<td>see text</td>
</tr>
<tr>
<td>Component (b)</td>
<td>$6(k-1)$</td>
<td>see text</td>
</tr>
<tr>
<td>Intrablock error</td>
<td>$(2rk^2-1)$</td>
<td>subtraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$-(2r+2k^2+12k -15)$</td>
</tr>
</tbody>
</table>

The component (b) sum of squares is computed as follows:

$$
\sum_{j=1}^{3} \beta_{jg} Q_{.jg} / q \quad \sum_{j=1}^{3} \sum_{k=1}^{2k} \beta_{jg} Q_{.jg} / q
$$
The component (a) sum of squares is the interaction of block totals, \( Y_{jg} \) with the \( q \) replicates which have the same basic arrangement within sets of treatments 1 to \( k^2 \) and \( k^2 + 1 \) to \( 2k^2 \).

Both the \( A \times \) replicates and the component (a) mean squares have an expectation \( \sigma_e^2 + k \sigma_B^2 \); the expectation of the component (b) mean square is \( \sigma_e^2 + 2/3 k \sigma_B^2 \) where \( \sigma_e^2 \) is the variance of plots within block errors and \( \sigma_B^2 \) is the variance of block errors on a per plot basis.

The preceding analysis, developed by Federer and Plaisted (8), was applied to the data for total yield for each of the three locations. It appeared subsequently that a slightly different method of analysis is desirable, because the mean square for \( A \times \) replicates, in Table 3, is an estimate of \( \sigma_e^2 + 10 \sigma_B^2 \) and thus provides information on the weights to be used in the combination of interblock and intrablock information. Specific gravity and tuber appearance data therefore, were computed by this modified analysis. The equations for estimation of the weights are as follows:

\[
\hat{\sigma}_e^2 = \text{intrablock error mean square},
\]

\[
113\hat{\sigma}_e^2 + 950\hat{\sigma}_B^2 = \text{pooled sum of squares for } A \times \text{replicates, and component (a) and component (b) of the sum of squares for blocks eliminating treatments in Table 3.}
\]

The intrablock weight, \( W \), is estimated, in the customary manner,
by \( \frac{1}{\sigma_e^2} \) and the interblock weight by \( W' = \frac{1}{\sigma_e^2 + 10\sigma^2} \). The nature of the estimation procedure is that A, the comparison of treatments 1-100 versus 101-200 is estimated by the interblock comparisons; comparisons among treatments 1-100 and 101-200 are estimated by the usual procedure for the triple lattice. Thus, the comparison of treatments 1-100 versus treatments 101-200 is estimated by the observed mean difference, while comparisons within the first set of 100 and within the second set of 100 are estimated by the standard formulae; given, for example, by Kempthorne (25b, pp. 454-455). The letters \( w \) and \( w' \) are used to denote the estimates of \( W \) and \( W' \) respectively.

Then, the variances of treatment differences are as follows:

1. difference of two treatments which occur together in a block,

\[
V(\hat{t}_i - \hat{t}_j) = \frac{1}{10} \left[ \frac{2}{2w+w'} + \frac{8}{3w} \right] ;
\]

2. difference of two treatments within a set which do not occur together in a block,

\[
V(\hat{t}_i - \hat{t}_j) = \frac{1}{10} \left[ \frac{3}{2w+w'} + \frac{7}{3w} \right] ;
\]

3. difference of treatments in different sets,

\[
V(\hat{t}_i - \hat{t}_j) = \frac{1}{100} \left[ \frac{27}{2w+w'} + \frac{72}{3w} + \frac{1}{3w'} \right] .
\]

It would be possible to take account, in analysis of line by tester crosses, of these differences in variances, but this would be rather complicated and tedious. Because the crosses were assigned at
random to the two sets of 100 entries, it is appropriate to use half the average variance of all possible differences of pairs of treatments as the effective error mean square to be associated with each final treatment total. This effective error variance was found to be

\[
\frac{36}{199} \left[ \frac{27}{2w} + \frac{72}{3w} + \frac{1}{5w} \right]
\]

and this is designated by \( \hat{\sigma}^2 \).

To estimate the variances ascribed to general and specific combining ability, the adjusted treatment totals were arranged in a two-way layout as indicated below:

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>j</td>
<td>( x_{1j} )</td>
<td>( x_{2j} )</td>
<td>( x_{3j} )</td>
<td>( x_{4j} )</td>
<td>( x_{5j} )</td>
<td>( x_{6j} )</td>
</tr>
<tr>
<td>.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this layout, if the cross of line \( j \) and tester \( i \) was made, the entry is \( x_{ij} \), the adjusted treatment total for that cross. A feature of the situation which presents difficulty is that the layout is incomplete, since some crosses could not be made. Just what this non-orthogonality does to the validity of the ensuing analysis is a moot point. It is assumed in the analysis that absence of a line-tester
combination is due to the particular circumstance at the time and not
to the genetic properties of the line and tester.

Table 4 gives a non-orthogonal analysis of variance which was
used to estimate the components of variance for lines, testers, and
interaction of lines and testers.

Table 4. Analysis of variance for estimating line, tester, and line
\( x \) tester variance components

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Sum of squares(^a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testers T-1</td>
<td></td>
<td>( \sum_{j=1}^{6} \frac{x_{i,j}^2}{6K_{i.j}} ) - c.f.</td>
</tr>
<tr>
<td>Lines L-1</td>
<td></td>
<td>( \sum_{i=1}^{45} \frac{x_{i,j}^2}{6K_{i.j}} ) - c.f.</td>
</tr>
<tr>
<td>Testers x Lines</td>
<td>( \sum (L-1) ) within testers - (L-1)</td>
<td>( \sum_{i} \sum_{j} \frac{K_{ij} x_{ij}^2}{6} - \sum_{i} \frac{x_{i}^2}{6K_{i.j}} ) - ( \sum_{j} \frac{x_{i,j}^2}{6K_{i.j}} ) + c.f.</td>
</tr>
</tbody>
</table>

\(^a\)\( K_{ij} = 0 \) if the \( i^{th} \) tester was not crossed to the \( j^{th} \) line
\( K_{ij} = 1 \) if the \( i^{th} \) tester was crossed to the \( j^{th} \) line
\( K_{i.j} = \sum_{j} K_{ij} \)
\( K_{.j} = \sum_{i} K_{ij} \)
The expectations of the sum of squares in Table 4 were developed by the use of the model,

\[ Y_{ghij} = n_{ghij} m_{ij} (u + \rho_g + \alpha_i + \gamma_j + \alpha_{ij} + e_{ghij}), \]

where \( u \) = grand mean,
\( \rho_g \) = \( g \)th replicate effect,
\( \alpha_i \) = \( i \)th tester effect,
\( \gamma_j \) = \( j \)th line effect,
\( n_{ghij} \) = one if the \( ij \)th treatment occurs in the \( h \)th block of the \( g \)th replication, otherwise it equals zero,
\( m_{ij} \) = one if the \( i \)th tester was crossed to the \( j \)th line,

and are expressed by the following formulae:

**Testers**

\( (a-1)\sigma^2 + r(a-l)\alpha^2 + r(a-l)\gamma^2 + r(a-l)\alpha\gamma + r(a-l)^2 \sigma^2_{\alpha\gamma} \)

**Lines**

\( (c-1)\sigma^2 + r(c-l)\gamma^2 + r(c-l)\alpha\gamma + r(c-l)^2 \sigma^2_{\alpha\gamma} \)

**Lines x Testers**

\( (m.-a-c+1)\sigma^2 + r(m.-a-c+1)\alpha^2_{\alpha\gamma} + r(-a \frac{1}{m.} \sum_j m_{ij}^2)\gamma^2 + r(-c \frac{1}{m.} \sum_i m_{ij}^2)\alpha^2 + r(-c \frac{1}{m.} \sum_i m_{ij}^2)\sigma^2_{\alpha\gamma} \)

In these formulae, \( (a) \) equals the number of testers and \( (c) \) equals the number of lines.

The expected mean squares are obtained by dividing by the appropriate degrees of freedom for testers \( (a-1) \), lines \( (c-1) \), and
lines x testers (c-1 within each tester minus c-1). The calculated expected mean squares are given in Table 5.

Table 5. Expected mean squares for testers, lines, and testers x lines

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Expected mean squares&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testers</td>
<td>5</td>
<td>$\sigma^2 + 6 \sigma_{lxt}^2 + 188.91 \sigma_t^2 + 1.63 \sigma_l^2$</td>
</tr>
<tr>
<td>Lines</td>
<td>44</td>
<td>$\sigma^2 + 6 \sigma_{lxt}^2 + 1.69 \sigma_t^2 + 25.28 \sigma_l^2$</td>
</tr>
<tr>
<td>Testers x Lines</td>
<td>140</td>
<td>$\sigma^2 + 6 \sigma_{lxt}^2 - 0.53 \sigma_t^2 - 0.06 \sigma_l^2$</td>
</tr>
</tbody>
</table>

<sup>a</sup>The quantity $\sigma^2$ is the effective error mean square previously described.

It was also considered worthwhile to determine the effects of the six testers, assuming both testers and lines as fixed with no interaction. The following mathematical model was used:

$$Y_{ij} = u + t_i + l_j + e_{ij},$$

where $Y_{ij}$ = the response of the cross between the $i^{th}$ tester and the $j^{th}$ line,

$u$ = grand mean,

$t_i$ = effect of the $i^{th}$ tester,

$l_j$ = effect of the $j^{th}$ line,

$e_{ij}$ = the residual deviation, which is distributed with a constant variance and uncorrelated error.
The least square procedure of fitting $Y_{ij} = u + t_i + l_j$ was followed to construct the normal equations; these equations can be expressed in matrix form as follows:

$$
\begin{bmatrix}
  t_1 \\
  . \\
  . \\
  . \\
  . \\
  . \\
  l_{45}
\end{bmatrix}
= 
\begin{bmatrix}
  a_{11} & \cdots & \cdots & \cdots & a_{145} \\
  . & \vdots & \vdots & \vdots & . \\
  . & . & . & . & . \\
  . & . & . & . & . \\
  a_{451} & \cdots & \cdots & \cdots & a_{4545}
\end{bmatrix}^{-1}
\begin{bmatrix}
  t_1 \\
  . \\
  . \\
  . \\
  . \\
  . \\
  l_{45}
\end{bmatrix},
$$

where $t_i = \text{the estimated effect of the } i^{th} \text{ tester},$

$l_j = \text{the estimated effect of the } j^{th} \text{ line},$

$a_{11} - a_{4545} = \text{the elements of the matrix of coefficients},$

$T_i = \text{the total for the } i^{th} \text{ tester},$

$L_j = \text{the total for the } j^{th} \text{ line}.$

Since the tester effects were of prime interest, a mathematical procedure of absorbing the lines was used to reduce the $45 \times 45$ matrix of coefficients to the following $6 \times 6$ matrix:

$$
\begin{bmatrix}
  t_1 \\
  t_2 \\
  . \\
  . \\
  t_6
\end{bmatrix}
= 
\begin{bmatrix}
  b_{11} & \cdots & \cdots & \cdots & b_{16} \\
  . & \vdots & \vdots & \vdots & . \\
  . & . & . & . & . \\
  . & . & . & . & . \\
  b_{61} & \cdots & \cdots & \cdots & b_{66}
\end{bmatrix}^{-1}
\begin{bmatrix}
  T_1 \\
  . \\
  . \\
  . \\
  T_6
\end{bmatrix}.
The \( b_{ij} \)'s are the elements of the matrix of coefficients following the process of absorption. This matrix was then inverted after imposing the condition that the \( \sum \hat{t}_i = 0 \). The matrix equation was then solved to determine the effect of each tester.

In order to assess interactions of lines, testers, and lines x testers with locations (with an associated subscript \( p \) because the subscript \( l \) is already used for lines), a subset of the data consisting of eight lines crossed with all the six testers was evaluated by a complete orthogonal analysis of variance of the adjusted treatment means. The structure of the analysis of variance is given in Table 6. In this table, the \( \sigma^2 \) is again the effective error mean square referred to previously.

Table 6. Analysis of variance for an orthogonal set of 48 crosses

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Expected mean squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lines</td>
<td>7</td>
<td>( \sigma^2 + \sigma^2_{l+txp} + 6\sigma^2_{lxp} + 3\sigma^2_{lxt} + 18 \sigma^2_1 )</td>
</tr>
<tr>
<td>Lines x Places</td>
<td>14</td>
<td>( \sigma^2 + \sigma^2_{l+txp} + 6\sigma^2_{lxp} )</td>
</tr>
<tr>
<td>Testers</td>
<td>5</td>
<td>( \sigma^2 + \sigma^2_{l+txp} + 8\sigma^2_{txp} + 3\sigma^2_{lxt} + 24 \sigma^2_t )</td>
</tr>
<tr>
<td>Testers x Places</td>
<td>19</td>
<td>( \sigma^2 + \sigma^2_{l+txp} + 8\sigma^2_{txp} )</td>
</tr>
<tr>
<td>Lines x Testers</td>
<td>35</td>
<td>( \sigma^2 + \sigma^2_{l+txp} + 3\sigma^2_{lxt} )</td>
</tr>
<tr>
<td>Lines x Testers x Places</td>
<td>70</td>
<td>( \sigma^2 + \sigma^2_{l+txp} )</td>
</tr>
</tbody>
</table>
EXPERIMENTAL RESULTS

Yield

The analyses of variance for Ithaca, Riverhead, and Clear Lake are shown in Tables 7, 8, and 9, respectively. Total variability appeared to be high at all locations. This was revealed by coefficients of variability of 24.2 percent at Ithaca, New York, 17.6 percent at Riverhead, New York, and 21.7 percent at Clear Lake, Iowa. Some of this variability appeared to be the result of sporadic virus infection of seedling plants in 1957. No attempt was made to index the crosses for any of the virus diseases.

Differences among crosses were found to be statistically significant at the one percent level at each of the three locations. The relatively low mean square for crosses 1-100 versus 101-200 seemed to verify the assumptions that the crosses had been randomly assigned to each triple lattice group and that the sample size was large enough in each group to be representative of this experimental population.

Yields for all tester x line crosses are shown in Tables 10, 11, and 12, for Ithaca, Riverhead, and Clear Lake, respectively. The mean yield of each tester represents performance in a wide variety of crosses and is therefore a relative measure of its general combining ability. As shown by the standard error of each mean, significant differences between averages of tester performance were not apparent at any location. This lack of significance suggests that general
combining ability may be of relatively little prominence in the present study. Within each of the testers, however, the range of yield values representing individual crosses indicates the relative magnitude of specific combining ability. For example, the Ithaca location, TL1859 x line 2 yielded 146.2 pounds compared to a mean for this tester of 111.3 pounds.

Table 7. Analysis of variance for total yield at Ithaca, New York

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Crosses 1-100 versus 101-200</td>
<td>1</td>
<td>8.416</td>
</tr>
<tr>
<td>Error (a)</td>
<td>5</td>
<td>113.442</td>
</tr>
<tr>
<td>Crosses within groups (ignoring blocks)</td>
<td>198</td>
<td>60.466**</td>
</tr>
<tr>
<td>Blocks within groups (eliminating crosses)</td>
<td>108</td>
<td>90.952</td>
</tr>
<tr>
<td>Component (a)</td>
<td>54</td>
<td>97.062</td>
</tr>
<tr>
<td>Component (b)</td>
<td>54</td>
<td>84.841</td>
</tr>
<tr>
<td>Intrablock error</td>
<td>882</td>
<td>16.696</td>
</tr>
</tbody>
</table>

** Denotes significance at the one percent level
Table 8. Analysis of variance for total yield at Riverhead, New York

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Crosses 1-100 versus 101-200</td>
<td>1</td>
<td>3.330</td>
</tr>
<tr>
<td>Error (a)</td>
<td>5</td>
<td>152.200</td>
</tr>
<tr>
<td>Crosses within groups (ignoring blocks)</td>
<td>198</td>
<td>56.112**</td>
</tr>
<tr>
<td>Blocks within groups (eliminating crosses)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component (a)</td>
<td>54</td>
<td>63.424</td>
</tr>
<tr>
<td>Component (b)</td>
<td>54</td>
<td>52.048</td>
</tr>
<tr>
<td>Intrablock error</td>
<td>882</td>
<td>9.359</td>
</tr>
</tbody>
</table>

** Denotes significance at the one percent level

Table 9. Analysis of variance for total yield at Clear Lake, Iowa

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Crosses 1-100 versus 101-200</td>
<td>1</td>
<td>2.891</td>
</tr>
<tr>
<td>Error (a)</td>
<td>5</td>
<td>22.205</td>
</tr>
<tr>
<td>Crosses within groups (ignoring blocks)</td>
<td>198</td>
<td>41.924**</td>
</tr>
<tr>
<td>Blocks within groups (eliminating crosses)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Component (a)</td>
<td>54</td>
<td>30.223</td>
</tr>
<tr>
<td>Component (b)</td>
<td>54</td>
<td>28.834</td>
</tr>
<tr>
<td>Intrablock error</td>
<td>882</td>
<td>10.105</td>
</tr>
</tbody>
</table>

** Denotes significance at the one percent level
10. Adjusted total yields, in pounds, of line x tester crosses grown at Ithaca, New York

<table>
<thead>
<tr>
<th>Line</th>
<th>Katahdin</th>
<th>TL1859</th>
<th>B962-32</th>
<th>ND457-1</th>
<th>X96-56</th>
<th>B3131-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>95.4</td>
<td>114.6</td>
<td>133.8</td>
<td>103.2</td>
<td></td>
<td>135.0</td>
</tr>
<tr>
<td>2</td>
<td>146.4</td>
<td></td>
<td>111.0</td>
<td>87.6</td>
<td></td>
<td>122.4</td>
</tr>
<tr>
<td>3</td>
<td>104.4</td>
<td></td>
<td>111.6</td>
<td></td>
<td></td>
<td>84.6</td>
</tr>
<tr>
<td>4</td>
<td>102.6</td>
<td>88.2</td>
<td>91.2</td>
<td>105.5</td>
<td>153.0</td>
<td>75.0</td>
</tr>
<tr>
<td>5</td>
<td>105.0</td>
<td>40.8</td>
<td>120.0</td>
<td>97.2</td>
<td>69.6</td>
<td>43.8</td>
</tr>
<tr>
<td>6</td>
<td>116.4</td>
<td>132.0</td>
<td>89.4</td>
<td>120.6</td>
<td>81.0</td>
<td>82.2</td>
</tr>
<tr>
<td>7</td>
<td>82.2</td>
<td>123.0</td>
<td>108.0</td>
<td>124.8</td>
<td>70.8</td>
<td>106.2</td>
</tr>
<tr>
<td>8</td>
<td>72.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>121.2</td>
<td>114.6</td>
<td>111.3</td>
<td>97.4</td>
<td>96.0</td>
<td>99.0</td>
</tr>
<tr>
<td>10</td>
<td>99.6</td>
<td>122.4</td>
<td></td>
<td></td>
<td>94.2</td>
<td>132.0</td>
</tr>
<tr>
<td>11</td>
<td>117.6</td>
<td>104.4</td>
<td>87.6</td>
<td>111.6</td>
<td>155.4</td>
<td>118.2</td>
</tr>
<tr>
<td>12</td>
<td>142.2</td>
<td>119.4</td>
<td>98.4</td>
<td>85.8</td>
<td>75.0</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>91.8</td>
<td>115.8</td>
<td>90.0</td>
<td>100.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>84.6</td>
<td>137.4</td>
<td>100.8</td>
<td>73.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>131.4</td>
<td>112.8</td>
<td></td>
<td>103.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>85.2</td>
<td>94.2</td>
<td>101.4</td>
<td>120.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>71.4</td>
<td>118.2</td>
<td>65.4</td>
<td>79.8</td>
<td>121.8</td>
<td>72.0</td>
</tr>
<tr>
<td>18</td>
<td>95.4</td>
<td>117.6</td>
<td>88.2</td>
<td>77.4</td>
<td>76.8</td>
<td>112.8</td>
</tr>
<tr>
<td>19</td>
<td>109.8</td>
<td>79.8</td>
<td>96.0</td>
<td>118.8</td>
<td>119.4</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>88.2</td>
<td>140.4</td>
<td>103.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>114.6</td>
<td>118.8</td>
<td>77.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>84.6</td>
<td>117.0</td>
<td>58.2</td>
<td>117.0</td>
<td>86.4</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>84.6</td>
<td>111.0</td>
<td>78.6</td>
<td>69.0</td>
<td>84.6</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>79.8</td>
<td>49.8</td>
<td>83.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>144.6</td>
<td>82.8</td>
<td>112.8</td>
<td>104.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>109.8</td>
<td>139.2</td>
<td>106.2</td>
<td>85.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>102.0</td>
<td>146.4</td>
<td></td>
<td>88.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>118.8</td>
<td>111.6</td>
<td>93.0</td>
<td>100.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>76.8</td>
<td>48.0</td>
<td>107.4</td>
<td>128.4</td>
<td>99.6</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>108.6</td>
<td>76.8</td>
<td>79.8</td>
<td>58.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>91.2</td>
<td>108.0</td>
<td>108.0</td>
<td>90.0</td>
<td>97.2</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>82.8</td>
<td>140.4</td>
<td>108.6</td>
<td>93.0</td>
<td>98.4</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>93.6</td>
<td>108.6</td>
<td>65.4</td>
<td>99.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>97.2</td>
<td>111.0</td>
<td>96.0</td>
<td>90.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>123.0</td>
<td>142.8</td>
<td>118.8</td>
<td>96.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>93.6</td>
<td>129.6</td>
<td>124.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>114.6</td>
<td>123.6</td>
<td>93.6</td>
<td>74.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>96.6</td>
<td>96.6</td>
<td>84.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>109.2</td>
<td>120.0</td>
<td>73.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>81.6</td>
<td>78.0</td>
<td>102.6</td>
<td>59.4</td>
<td>75.6</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>78.0</td>
<td>98.4</td>
<td>90.2</td>
<td>109.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>79.0</td>
<td>79.2</td>
<td>139.2</td>
<td>119.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>149.4</td>
<td>70.2</td>
<td>90.6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>98.4</td>
<td>60.6</td>
<td>125.4</td>
<td>118.2</td>
<td>123.0</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>129.0</td>
<td>97.8</td>
<td>108.0</td>
<td>125.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>99.6</td>
<td>111.3</td>
<td>97.4</td>
<td>96.0</td>
<td>99.0</td>
<td>99.8</td>
</tr>
<tr>
<td>s_x</td>
<td>3.0</td>
<td>4.2</td>
<td>3.3</td>
<td>3.3</td>
<td>3.4</td>
<td>4.5</td>
</tr>
</tbody>
</table>

* a 180 square feet
Table 11. Adjusted total yields, in pounds, of line x tester crosses grown at Riverhead, New York

<table>
<thead>
<tr>
<th>Line</th>
<th>Katahdin</th>
<th>TL1859</th>
<th>B962-32</th>
<th>ND457-1</th>
<th>X96-56</th>
<th>B3131-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>112.8</td>
<td>119.4</td>
<td>132.0</td>
<td>102.6</td>
<td>57.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>115.8</td>
<td>146.4</td>
<td>117.0</td>
<td>74.4</td>
<td>91.2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>90.0</td>
<td>109.2</td>
<td>97.2</td>
<td>95.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>94.8</td>
<td>120.6</td>
<td>106.2</td>
<td>113.4</td>
<td>111.6</td>
<td>121.2</td>
</tr>
<tr>
<td>5</td>
<td>118.2</td>
<td>107.4</td>
<td>102.0</td>
<td>100.2</td>
<td>100.8</td>
<td>89.4</td>
</tr>
<tr>
<td>6</td>
<td>87.6</td>
<td>125.4</td>
<td>102.6</td>
<td>112.8</td>
<td>124.8</td>
<td>106.2</td>
</tr>
<tr>
<td>7</td>
<td>70.8</td>
<td>113.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>91.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>96.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>87.6</td>
<td>124.8</td>
<td>98.4</td>
<td>100.4</td>
<td>110.4</td>
<td>70.8</td>
</tr>
<tr>
<td>11</td>
<td>73.2</td>
<td>116.4</td>
<td>102.6</td>
<td>102.0</td>
<td>73.8</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>108.0</td>
<td>129.0</td>
<td>112.2</td>
<td>87.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>99.6</td>
<td>129.0</td>
<td>102.0</td>
<td>114.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>108.0</td>
<td>106.2</td>
<td>102.6</td>
<td>109.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>106.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>85.2</td>
<td>113.4</td>
<td>96.6</td>
<td>70.2</td>
<td>41.4</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>104.4</td>
<td>123.0</td>
<td>109.2</td>
<td>105.0</td>
<td>99.6</td>
<td>79.2</td>
</tr>
<tr>
<td>18</td>
<td>153.0</td>
<td>130.2</td>
<td>102.0</td>
<td>73.8</td>
<td>106.2</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>112.2</td>
<td>123.0</td>
<td>121.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>96.6</td>
<td>127.2</td>
<td>104.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>111.6</td>
<td>132.6</td>
<td>123.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></td>
<td>115.8</td>
<td>104.4</td>
<td>89.4</td>
<td>115.8</td>
<td>105.6</td>
</tr>
<tr>
<td>23</td>
<td>84.6</td>
<td>126.0</td>
<td>118.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>93.0</td>
<td>114.0</td>
<td>121.2</td>
<td>111.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>97.8</td>
<td>112.8</td>
<td>95.4</td>
<td>63.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>106.8</td>
<td>95.4</td>
<td></td>
<td>72.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td></td>
<td>145.8</td>
<td>92.4</td>
<td>107.4</td>
<td>110.4</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>97.2</td>
<td>92.4</td>
<td>61.2</td>
<td>96.6</td>
<td>85.8</td>
<td>102.6</td>
</tr>
<tr>
<td>29</td>
<td>86.4</td>
<td>133.8</td>
<td>124.2</td>
<td>76.8</td>
<td>79.2</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>118.8</td>
<td>123.0</td>
<td>106.8</td>
<td>67.8</td>
<td>76.8</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>123.6</td>
<td>82.2</td>
<td>106.8</td>
<td>88.8</td>
<td>116.4</td>
<td>111.6</td>
</tr>
<tr>
<td>32</td>
<td>119.4</td>
<td>119.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>133.8</td>
<td>82.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>123.0</td>
<td>106.8</td>
<td>88.8</td>
<td>116.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>102.6</td>
<td>48.0</td>
<td>94.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>105.0</td>
<td>120.6</td>
<td>66.6</td>
<td>91.8</td>
<td>73.8</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>102.0</td>
<td>85.8</td>
<td>127.8</td>
<td>124.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td></td>
<td>73.8</td>
<td>75.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>109.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>84.6</td>
<td>104.4</td>
<td>94.2</td>
<td>56.4</td>
<td>73.8</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>90.6</td>
<td>81.6</td>
<td></td>
<td>72.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>72.0</td>
<td>101.4</td>
<td>103.8</td>
<td>129.0</td>
<td>121.2</td>
<td>97.2</td>
</tr>
<tr>
<td>43</td>
<td>136.2</td>
<td>129.0</td>
<td>103.8</td>
<td>126.0</td>
<td>93.6</td>
<td>115.8</td>
</tr>
<tr>
<td>44</td>
<td>124.2</td>
<td>136.2</td>
<td>97.8</td>
<td>123.6</td>
<td>128.4</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td></td>
<td>124.2</td>
<td>103.8</td>
<td>126.0</td>
<td>93.6</td>
<td>115.8</td>
</tr>
</tbody>
</table>

Mean 101.0 114.8 101.4 100.3 99.0 95.0

\( \text{sd} \) 2.5 2.9 3.2 3.1 4.2 4.1

\( a \) 180 square feet
Table 12. Adjusted total yields, in pounds, of line x tester crosses grown at Clear Lake, Iowa

<table>
<thead>
<tr>
<th>Line</th>
<th>Katahdin</th>
<th>TL1859</th>
<th>B962-32</th>
<th>ND457-1</th>
<th>X96-56</th>
<th>B3131-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58.3</td>
<td>78.8</td>
<td>94.2</td>
<td>76.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>89.8</td>
<td>82.1</td>
<td>102.1</td>
<td>95.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>73.0</td>
<td>82.1</td>
<td>104.5</td>
<td>79.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>97.3</td>
<td>85.8</td>
<td>84.5</td>
<td>87.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>81.4</td>
<td>73.6</td>
<td>84.4</td>
<td>56.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>111.0</td>
<td>73.6</td>
<td>116.4</td>
<td>92.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>73.6</td>
<td>73.6</td>
<td>116.4</td>
<td>104.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>87.4</td>
<td>80.0</td>
<td>85.4</td>
<td>110.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>90.7</td>
<td>77.4</td>
<td>85.4</td>
<td>82.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>92.5</td>
<td>78.1</td>
<td>92.0</td>
<td>90.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>101.5</td>
<td>104.5</td>
<td>92.0</td>
<td>69.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>92.5</td>
<td>79.3</td>
<td>84.4</td>
<td>76.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>88.2</td>
<td>96.3</td>
<td>84.4</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>116.4</td>
<td>86.0</td>
<td>84.4</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>79.8</td>
<td>80.0</td>
<td>85.4</td>
<td>63.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>74.3</td>
<td>67.1</td>
<td>85.4</td>
<td>63.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>103.4</td>
<td>103.4</td>
<td>72.3</td>
<td>73.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>93.4</td>
<td>93.4</td>
<td>72.3</td>
<td>73.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>92.9</td>
<td>92.9</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>92.0</td>
<td>92.0</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>82.6</td>
<td>82.6</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>97.0</td>
<td>97.0</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>92.9</td>
<td>92.9</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>92.9</td>
<td>92.9</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>87.5</td>
<td>87.5</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>67.1</td>
<td>67.1</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>93.4</td>
<td>93.4</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>81.1</td>
<td>81.1</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>78.0</td>
<td>78.0</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>95.0</td>
<td>95.0</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>107.3</td>
<td>107.3</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>108.5</td>
<td>108.5</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>112.5</td>
<td>112.5</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>113.6</td>
<td>113.6</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>112.5</td>
<td>112.5</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>92.9</td>
<td>92.9</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>98.9</td>
<td>98.9</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>109.7</td>
<td>109.7</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>121.6</td>
<td>121.6</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>82.3</td>
<td>82.3</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>96.1</td>
<td>96.1</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>100.2</td>
<td>100.2</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>103.5</td>
<td>103.5</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>94.0</td>
<td>94.0</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>65.3</td>
<td>65.3</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>92.5</td>
<td>92.5</td>
<td>83.1</td>
<td>72.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$s_2^2 = 2.9$
Estimates of the variance components used to measure general and specific combining ability at each location are presented in Tables 13, 14, and 15. The line x tester component was relatively large in comparison with those for lines and testers at each of the three locations. Therefore, it appears that specific combining ability was more important than general combining ability in determining yield at each of the locations. Since an incomplete set of crosses was used to estimate these components, the values were not measured by an F-test. However, the consistency of the results over three varied locations supports their biological significance.

The combined analysis for estimating general and specific combining ability is presented in Table 16. In this analysis, an orthogonal table of 48 of the 190 crosses was used to compute the variance components. The line x tester component was found to be approximately twice that of the tester or line, again indicating the importance of specific combining ability. The specific combining ability effects appeared to interact more with the environment than did general combining ability effects. This is shown by comparisons between the estimated components for line x tester x location and the components for tester x location and line x location. The line x tester x location mean square was shown to be statistically significant at the one percent level. This significance was revealed by using the effective error mean square, divided by six, as the denominator in the F-test.
Table 13. Analysis of variance for estimating general and specific combining ability for total yield at Ithaca, New York

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
<th>Estimated variance component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testers</td>
<td>5</td>
<td>188.296</td>
<td>$\sigma^2_t = 0.579$</td>
</tr>
<tr>
<td>Lines</td>
<td>44</td>
<td>89.619</td>
<td>$\sigma^2_1 = 0.412$</td>
</tr>
<tr>
<td>Lines x Testers</td>
<td>140</td>
<td>77.888</td>
<td>$\sigma^2_{lxt} = 10.254$</td>
</tr>
</tbody>
</table>

Table 14. Analysis of variance for estimating general and specific combining ability for total yield at Riverhead, New York

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
<th>Estimated variance component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testers</td>
<td>5</td>
<td>261.170</td>
<td>$\sigma^2_t = 1.099$</td>
</tr>
<tr>
<td>Lines</td>
<td>44</td>
<td>76.643</td>
<td>$\sigma^2_1 = 0.892$</td>
</tr>
<tr>
<td>Lines x Testers</td>
<td>140</td>
<td>51.595</td>
<td>$\sigma^2_{lxt} = 7.145$</td>
</tr>
</tbody>
</table>
Table 15. Analysis of variance for estimating general and specific combining ability for total yield at Clear Lake, Iowa

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
<th>Estimated variance component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testers</td>
<td>5</td>
<td>57.386</td>
<td>$\sigma_t^2 = 0.143$</td>
</tr>
<tr>
<td>Lines</td>
<td>44</td>
<td>63.625</td>
<td>$\sigma_l^2 = 1.395$</td>
</tr>
<tr>
<td>Lines x Testers</td>
<td>140</td>
<td>27.954</td>
<td>$\sigma_{lxt}^2 = 3.001$</td>
</tr>
</tbody>
</table>

Table 16. Analysis of variance of combined data for estimating general and specific combining ability for total yield

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
<th>Estimated variance component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lines</td>
<td>7</td>
<td>18.353</td>
<td>$\sigma_l^2 = 0.701$</td>
</tr>
<tr>
<td>Lines x Places</td>
<td>14</td>
<td>9.337</td>
<td>$\sigma_{lxp}^2 = 0.205$</td>
</tr>
<tr>
<td>Testers</td>
<td>5</td>
<td>20.267</td>
<td>$\sigma_t^2 = 0.701$</td>
</tr>
<tr>
<td>Testers x Places</td>
<td>10</td>
<td>11.434</td>
<td>$\sigma_{txp}^2 = 0.416$</td>
</tr>
<tr>
<td>Lines x Testers</td>
<td>35</td>
<td>12.315</td>
<td>$\sigma_{lxt}^2 = 1.402$</td>
</tr>
<tr>
<td>Lines x Testers x Places</td>
<td>70</td>
<td>8.108</td>
<td>$\sigma_{ltxp}^2 = 6.099$</td>
</tr>
</tbody>
</table>

*Orthogonal table of 48 line x tester crosses used for computations*
In Table 17 the direct effect of testers is shown for each location and for combined locations. This direct effect primarily includes the yield contribution of the tester. Effects of individual lines had been mathematically absorbed. These data revealed that the greatest effect was due to tester TL1859. This effect was consistent at each location and in the combined analysis. B3131-8 gave the smallest effect over all locations. The tester effect calculated in this study apparently contains both specific and general effects. General combining ability differences among testers were shown to be insignificant and the importance of specific effects in this population was indicated from the estimated variance components. Therefore, it would seem that the large effect of TL1859 could be attributed primarily to specific combining ability, i.e., to non-additive gene action.

Table 17. Relative effects of testers in determining yield of crosses grown at Ithaca, New York, Riverhead, New York, Clear Lake, Iowa, and in combined locations

<table>
<thead>
<tr>
<th>Tester</th>
<th>Ithaca New York</th>
<th>Riverhead New York</th>
<th>Clear Lake Iowa</th>
<th>Combined locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katahdin</td>
<td>-20.8</td>
<td>-95.9</td>
<td>62.1</td>
<td>-18.2</td>
</tr>
<tr>
<td>TL1859</td>
<td>1093.3</td>
<td>1535.6</td>
<td>551.0</td>
<td>1059.9</td>
</tr>
<tr>
<td>B962-32</td>
<td>-518.9</td>
<td>-29.4</td>
<td>-222.3</td>
<td>-256.9</td>
</tr>
<tr>
<td>ND457-1</td>
<td>-510.5</td>
<td>-84.8</td>
<td>217.4</td>
<td>-125.9</td>
</tr>
<tr>
<td>X96-56</td>
<td>-34.4</td>
<td>-326.9</td>
<td>-169.6</td>
<td>-176.9</td>
</tr>
<tr>
<td>B3131-8</td>
<td>-8.7</td>
<td>-998.5</td>
<td>-438.6</td>
<td>-481.9</td>
</tr>
</tbody>
</table>

*Based upon total yield in pounds per 180 square feet*
Specific Gravity

Table 18 presents the analysis of variance at the Clear Lake location. Total variability was low with a coefficient of variability of 6.5 percent. If virus infections caused some of the variation in the trials, it is apparent that such infections have little or no effect on specific gravity, assuming that the infected plant lives to maturity. The differences between crosses were found to be statistically significant at the one percent level. The random sample of these crosses in each lattice group was felt to be effective, since no significant difference was found between crosses 1-100 and 101-200.

Table 18. Analysis of variance for specific gravity at Clear Lake, Iowa

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Crosses 1-100 versus 101-200</td>
<td>1</td>
<td>71.050</td>
</tr>
<tr>
<td>Crosses within groups (ignoring blocks)</td>
<td>198</td>
<td>94.978**</td>
</tr>
<tr>
<td>Blocks within groups (eliminating crosses)</td>
<td>108</td>
<td>28.376</td>
</tr>
<tr>
<td>Component (a)</td>
<td>54</td>
<td>32.785</td>
</tr>
<tr>
<td>Component (b)</td>
<td>54</td>
<td>37.835</td>
</tr>
<tr>
<td>Intrablock error</td>
<td>882</td>
<td>18.179</td>
</tr>
</tbody>
</table>

**Denotes significance at the one percent level
Table 19. Adjusted mean specific gravity of line x tester crosses grown at Clear Lake, Iowa

<table>
<thead>
<tr>
<th>Line</th>
<th>Katahdin</th>
<th>TL1859</th>
<th>B962-32</th>
<th>ND457-1</th>
<th>X96-56</th>
<th>B3131-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.064</td>
<td>1.066</td>
<td>1.068</td>
<td>1.065</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.058</td>
<td>1.059</td>
<td>1.067</td>
<td>1.060</td>
<td>1.066</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1.067</td>
<td>1.066</td>
<td>1.066</td>
<td>1.070</td>
<td>1.066</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>1.065</td>
<td>1.067</td>
<td>1.067</td>
<td>1.068</td>
<td>1.068</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>1.065</td>
<td>1.065</td>
<td>1.072</td>
<td>1.068</td>
<td>1.068</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1.057</td>
<td>1.063</td>
<td>1.066</td>
<td>1.060</td>
<td>1.060</td>
<td>1.063</td>
</tr>
<tr>
<td>7</td>
<td>1.059</td>
<td>1.061</td>
<td>1.066</td>
<td>1.062</td>
<td>1.061</td>
<td>1.068</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>1.058</td>
<td></td>
<td>1.066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>1.064</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>1.064</td>
<td>1.059</td>
<td>1.073</td>
<td>1.066</td>
<td>1.066</td>
<td>1.070</td>
</tr>
<tr>
<td>11</td>
<td>1.060</td>
<td>1.061</td>
<td></td>
<td>1.065</td>
<td>1.061</td>
<td>1.064</td>
</tr>
<tr>
<td>12</td>
<td>1.064</td>
<td>1.061</td>
<td>1.068</td>
<td>1.065</td>
<td>1.061</td>
<td>1.065</td>
</tr>
<tr>
<td>13</td>
<td>1.061</td>
<td>1.062</td>
<td>1.069</td>
<td>1.067</td>
<td>1.067</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>1.061</td>
<td>1.058</td>
<td>1.069</td>
<td>1.068</td>
<td>1.068</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>1.061</td>
<td></td>
<td>1.065</td>
<td>1.067</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>1.066</td>
<td>1.061</td>
<td>1.067</td>
<td>1.066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>1.071</td>
<td></td>
<td></td>
<td>1.071</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>1.063</td>
<td>1.059</td>
<td>1.068</td>
<td>1.064</td>
<td>1.064</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>1.065</td>
<td>1.065</td>
<td>1.072</td>
<td>1.067</td>
<td>1.071</td>
<td>1.074</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>1.065</td>
<td>1.066</td>
<td>1.072</td>
<td>1.073</td>
<td>1.067</td>
</tr>
<tr>
<td>21</td>
<td>1.063</td>
<td>1.065</td>
<td></td>
<td>1.070</td>
<td>1.063</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>1.065</td>
<td>1.067</td>
<td>1.073</td>
<td>1.066</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>1.056</td>
<td>1.061</td>
<td></td>
<td>1.070</td>
<td></td>
<td>1.064</td>
</tr>
<tr>
<td>24</td>
<td></td>
<td>1.067</td>
<td>1.070</td>
<td>1.070</td>
<td>1.066</td>
<td>1.070</td>
</tr>
<tr>
<td>25</td>
<td>1.066</td>
<td>1.067</td>
<td>1.072</td>
<td>1.072</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>1.070</td>
<td>1.067</td>
<td>1.070</td>
<td>1.064</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>1.061</td>
<td>1.062</td>
<td>1.066</td>
<td>1.067</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>1.061</td>
<td>1.063</td>
<td></td>
<td>1.065</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
<td>1.069</td>
<td>1.067</td>
<td>1.069</td>
<td>1.073</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>1.065</td>
<td>1.068</td>
<td>1.066</td>
<td>1.071</td>
<td>1.064</td>
<td>1.070</td>
</tr>
<tr>
<td>31</td>
<td>1.059</td>
<td>1.062</td>
<td>1.068</td>
<td>1.070</td>
<td>1.066</td>
<td>1.064</td>
</tr>
<tr>
<td>32</td>
<td>1.063</td>
<td>1.065</td>
<td>1.065</td>
<td>1.065</td>
<td>1.065</td>
<td>1.064</td>
</tr>
<tr>
<td>33</td>
<td>1.061</td>
<td></td>
<td>1.072</td>
<td>1.068</td>
<td>1.060</td>
<td>1.065</td>
</tr>
<tr>
<td>34</td>
<td>1.066</td>
<td>1.065</td>
<td>1.072</td>
<td>1.073</td>
<td>1.068</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>1.066</td>
<td>1.065</td>
<td>1.071</td>
<td>1.069</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>1.067</td>
<td>1.063</td>
<td>1.070</td>
<td>1.069</td>
<td>1.066</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>1.064</td>
<td>1.067</td>
<td>1.074</td>
<td>1.068</td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td></td>
<td>1.065</td>
<td>1.058</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39</td>
<td></td>
<td>1.063</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>1.060</td>
<td>1.059</td>
<td>1.065</td>
<td>1.065</td>
<td>1.064</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td></td>
<td>1.068</td>
<td>1.064</td>
<td>1.063</td>
<td>1.063</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>1.064</td>
<td>1.062</td>
<td>1.066</td>
<td>1.066</td>
<td>1.063</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td></td>
<td>1.064</td>
<td>1.067</td>
<td>1.067</td>
<td>1.064</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>1.067</td>
<td>1.065</td>
<td>1.076</td>
<td>1.071</td>
<td>1.070</td>
<td>1.070</td>
</tr>
<tr>
<td>45</td>
<td></td>
<td>1.071</td>
<td>1.068</td>
<td>1.068</td>
<td>1.071</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1.063</td>
<td>1.063</td>
<td>1.069</td>
<td>1.067</td>
<td>1.066</td>
<td>1.067</td>
</tr>
<tr>
<td>$s_X$</td>
<td>0.006</td>
<td>0.005</td>
<td>0.005</td>
<td>0.006</td>
<td>0.007</td>
<td>0.007</td>
</tr>
</tbody>
</table>
The mean specific gravity reading for each cross is presented in Table 19. The mean for tester B962-32 was found to be significantly greater than those for Katahdin and TL1859 at the one percent level. This suggests that B962-32 may be a better general combiner for specific gravity than Katahdin or TL1859. No measurable differences were found between other tester means. Most of the values for individual crosses seemed to correspond closely to the respective tester mean indicating a relatively small specific effect.

The analysis of variance for estimating general and specific combining ability is presented in Table 20. The tester and line components were approximately twice that of line x tester. This analysis suggests that general combining ability, or additive effects, may be more important than specific combining ability, or non-additive effects, in determining specific gravity.

Table 20. Analysis of variance for estimating general and specific combining ability for specific gravity at Clear Lake, Iowa

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
<th>Estimated variance component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testers</td>
<td>5</td>
<td>995.014</td>
<td>$\sigma^2_t = 5.033$</td>
</tr>
<tr>
<td>Lines</td>
<td>44</td>
<td>183.346</td>
<td>$\sigma^2_i = 5.519$</td>
</tr>
<tr>
<td>Lines x Testers</td>
<td>140</td>
<td>32.326</td>
<td>$\sigma^2_{ixt} = 2.858$</td>
</tr>
</tbody>
</table>
The relative tester effects calculated for specific gravity are as follows:

- Katahdin: -1611.8
- TL1859: -1404.1
- B962-32: 1740.2
- ND457-1: 721.8
- X96-56: -380.7
- B3131-8: 934.6

Testers B962-32, ND457-1, and B3131-8 had rather strong effects. The magnitude of individual tester means and variance components suggest that additive gene effects contribute to the differences found in these effects.

**Tuber Appearance**

The analysis of variance is presented in Table 21. The coefficient of variability for this characteristic at Clear Lake was found to be 22 percent. A significant difference at the five percent level was discovered between crosses 1-100 and 101-200. Although the distribution of crosses within each tester was found to be nearly equal between the two groups, the sample size may have been too small to represent the entire population of crosses for tuber rating. The reason for this could be the subjective nature of the tuber appearance ratings. It is doubtful if this difference has any significance regarding other tuber rating results, however. The differences between crosses within groups was found to be significant at the one percent level.
Thus, most of the total variation can be accounted for by effect of crosses.

Table 21. Analysis of variance for tuber appearance at Clear Lake, Iowa

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Crosses 1-100 versus 101-200</td>
<td>1</td>
<td>11.600*</td>
</tr>
<tr>
<td>Error (a)</td>
<td>5</td>
<td>1.530</td>
</tr>
<tr>
<td>Crosses within groups (ignoring blocks)</td>
<td>198</td>
<td>2.711**</td>
</tr>
<tr>
<td>Blocks within groups (eliminating crosses)</td>
<td>108</td>
<td>0.854</td>
</tr>
<tr>
<td>Component (a)</td>
<td>54</td>
<td>0.869</td>
</tr>
<tr>
<td>Component (b)</td>
<td>54</td>
<td>0.839</td>
</tr>
<tr>
<td>Intrablock error</td>
<td>882</td>
<td>0.695</td>
</tr>
</tbody>
</table>

* Denotes significance at the five percent level  
** Denotes significance at the one percent level

The cumulative tuber appearance indexes are presented for each cross in Table 22. The difference between the mean of tester ND457-1 and that of all other testers, except Katahdin, was found to be significant at the one percent level. The difference between ND457-1 and Katahdin was significant at the five percent level. All other differences between tester means were found to be non-significant. This indicates that ND457-1 has the best general combining ability of the six testers. When individual crosses of each
Table 22. Adjusted totals of tuber rating indexes of line x tester crosses grown at Clear Lake, Iowa

<table>
<thead>
<tr>
<th>Line</th>
<th>Katahdin</th>
<th>TL1859</th>
<th>B962-32</th>
<th>ND457-1</th>
<th>X96-56</th>
<th>B3131-8</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13.8</td>
<td>23.0</td>
<td>25.6</td>
<td></td>
<td></td>
<td>20.6</td>
</tr>
<tr>
<td>2</td>
<td>21.7</td>
<td>20.0</td>
<td>18.8</td>
<td>20.3</td>
<td>18.0</td>
<td>19.8</td>
</tr>
<tr>
<td>3</td>
<td>22.0</td>
<td>16.8</td>
<td>17.7</td>
<td>29.3</td>
<td>23.0</td>
<td>22.2</td>
</tr>
<tr>
<td>4</td>
<td>28.3</td>
<td>25.0</td>
<td>18.4</td>
<td>29.6</td>
<td>23.0</td>
<td>19.9</td>
</tr>
<tr>
<td>5</td>
<td>20.3</td>
<td>18.4</td>
<td>28.3</td>
<td>18.0</td>
<td>18.9</td>
<td>16.8</td>
</tr>
<tr>
<td>6</td>
<td>24.0</td>
<td>21.5</td>
<td>24.6</td>
<td>21.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>25.8</td>
<td>19.5</td>
<td>26.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>14.9</td>
<td>20.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>21.8</td>
<td>20.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>18.3</td>
<td>20.8</td>
<td>23.8</td>
<td>30.4</td>
<td>24.7</td>
<td>16.8</td>
</tr>
<tr>
<td>11</td>
<td>22.2</td>
<td>19.0</td>
<td>21.0</td>
<td>25.4</td>
<td>26.3</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>25.2</td>
<td>19.0</td>
<td>24.2</td>
<td>34.3</td>
<td></td>
<td>25.0</td>
</tr>
<tr>
<td>13</td>
<td>23.2</td>
<td>21.3</td>
<td>28.8</td>
<td>27.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>20.1</td>
<td>24.4</td>
<td>27.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>30.6</td>
<td>20.8</td>
<td>20.0</td>
<td>23.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17.1</td>
</tr>
<tr>
<td>18</td>
<td>29.7</td>
<td>22.3</td>
<td>22.0</td>
<td>25.8</td>
<td>21.7</td>
<td>20.3</td>
</tr>
<tr>
<td>19</td>
<td>21.5</td>
<td>21.7</td>
<td>20.4</td>
<td>22.2</td>
<td>17.7</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>11.2</td>
<td>18.1</td>
<td>23.7</td>
<td>15.3</td>
<td>23.7</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>19.8</td>
<td>20.9</td>
<td>21.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>25.8</td>
<td>23.6</td>
<td>29.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>22.7</td>
<td>25.4</td>
<td></td>
<td></td>
<td></td>
<td>18.3</td>
</tr>
<tr>
<td>24</td>
<td>21.0</td>
<td>17.6</td>
<td>27.7</td>
<td>25.7</td>
<td></td>
<td>19.0</td>
</tr>
<tr>
<td>25</td>
<td>16.7</td>
<td>14.5</td>
<td></td>
<td>18.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>25.0</td>
<td>16.0</td>
<td>22.1</td>
<td>23.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>22.2</td>
<td>23.5</td>
<td>24.0</td>
<td>24.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>25.2</td>
<td>24.9</td>
<td>19.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>18.5</td>
<td>27.2</td>
<td>27.4</td>
<td>25.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>23.8</td>
<td>21.6</td>
<td>22.4</td>
<td>26.0</td>
<td>28.0</td>
<td>22.0</td>
</tr>
<tr>
<td>31</td>
<td>23.2</td>
<td>19.5</td>
<td>22.2</td>
<td>32.3</td>
<td>21.0</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>24.9</td>
<td>23.0</td>
<td>20.3</td>
<td>21.2</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>25.6</td>
<td>22.8</td>
<td>24.0</td>
<td>19.0</td>
<td>25.1</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>26.0</td>
<td>18.7</td>
<td>21.5</td>
<td>27.2</td>
<td>18.9</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>27.3</td>
<td>22.0</td>
<td>17.0</td>
<td>24.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>21.4</td>
<td>19.8</td>
<td>23.5</td>
<td>20.6</td>
<td>18.8</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>21.4</td>
<td>18.6</td>
<td>20.4</td>
<td></td>
<td>16.1</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>25.9</td>
</tr>
<tr>
<td>39</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>26.3</td>
<td>22.7</td>
<td>28.3</td>
<td>21.1</td>
<td>21.7</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>28.6</td>
<td>26.8</td>
<td>25.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>24.0</td>
<td>23.3</td>
<td>23.2</td>
<td>21.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>20.3</td>
<td>21.8</td>
<td></td>
<td>19.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>18.0</td>
<td>25.0</td>
<td>22.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>18.8</td>
<td>23.0</td>
<td>28.5</td>
<td>19.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>23.7</td>
<td>20.2</td>
<td>22.0</td>
<td>26.4</td>
<td>21.4</td>
<td>21.0</td>
</tr>
<tr>
<td>s_g</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.6</td>
<td>0.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>
tester are compared with the tester mean, it is apparent that the specific effects are somewhat less than those found for yield data.

In Table 23 the variance components for estimating general and specific combining ability are presented. The estimates of these components seem to suggest that general and specific combining ability were of equal importance in determining tuber appearance in this population.

Table 23. Analysis of variance for estimating general and specific combining ability for tuber appearance at Clear Lake, Iowa.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>d.f.</th>
<th>Mean square</th>
<th>Estimated variance component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testers</td>
<td>5</td>
<td>261.170</td>
<td>$\sigma_t^2 = 0.138$</td>
</tr>
<tr>
<td>Lines</td>
<td>44</td>
<td>76.643</td>
<td>$\sigma_1^2 = 0.047$</td>
</tr>
<tr>
<td>Lines x Testers</td>
<td>140</td>
<td>51.595</td>
<td>$\sigma_{\text{Lxt}}^2 = 0.126$</td>
</tr>
</tbody>
</table>

The relative tester effects calculated for tuber appearance are as follows:

Katahdin 114.4

TL1859 -231.8

B962-32 -47.2

ND457-1 408.5

X96-56 -107.7

B3131-8 -136.2
Testers ND457-1 and Katahdin had the largest relative effects. Both of these clones have been used extensively as parents in breeding programs and have been noted for the excellent tuber appearance transmitted to their progenies.

Relationship between Testers and Lines

Of the 190 crosses used in this study, 70 were between testers and lines having a common parent within the previous two generations. As shown in Table 1, tester TL1859 was related to 26 of the 39 lines with which it was crossed, and tester B3131-8 was related to 12 of a total of 24 lines.

A comparison of data pooled for related and unrelated crosses of each tester revealed no substantial difference for yield, specific gravity or tuber appearance. The results are shown in Tables 24, 25, and 26, respectively. These data suggest that the relationship between lines and testers apparently had little effect on yield, specific gravity, or tuber appearance.

Table 24. Pooled yield of crosses involving related and unrelated parents

<table>
<thead>
<tr>
<th>Tester</th>
<th>Related crosses</th>
<th>Unrelated crosses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katahdin</td>
<td>95.1</td>
<td>96.2</td>
</tr>
<tr>
<td>TL1859</td>
<td>107.9</td>
<td>100.8</td>
</tr>
<tr>
<td>B962-32</td>
<td>90.8</td>
<td>95.8</td>
</tr>
<tr>
<td>ND457-1</td>
<td>92.2</td>
<td>96.2</td>
</tr>
<tr>
<td>X96-56</td>
<td>92.6</td>
<td>94.7</td>
</tr>
<tr>
<td>B3131-8</td>
<td>91.0</td>
<td>93.3</td>
</tr>
</tbody>
</table>

*Based upon total yield in pounds per 180 square feet*
Table 25. Pooled mean specific gravity readings of crosses involving related and unrelated parents

<table>
<thead>
<tr>
<th>Tester</th>
<th>Related crosses</th>
<th>Unrelated crosses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katahdin</td>
<td>1.062</td>
<td>1.063</td>
</tr>
<tr>
<td>TL1859</td>
<td>1.063</td>
<td>1.064</td>
</tr>
<tr>
<td>B962-32</td>
<td>1.068</td>
<td>1.069</td>
</tr>
<tr>
<td>ND457-1</td>
<td>1.066</td>
<td>1.066</td>
</tr>
<tr>
<td>X96-56</td>
<td>1.065</td>
<td>1.066</td>
</tr>
<tr>
<td>B3131-8</td>
<td>1.066</td>
<td>1.068</td>
</tr>
</tbody>
</table>

Table 26. Pooled tuber appearance indexes of crosses involving related and unrelated parents

<table>
<thead>
<tr>
<th>Tester</th>
<th>Related crosses</th>
<th>Unrelated crosses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Katahdin</td>
<td>23.2</td>
<td>23.8</td>
</tr>
<tr>
<td>TL1859</td>
<td>20.9</td>
<td>18.9</td>
</tr>
<tr>
<td>B962-32</td>
<td>22.8</td>
<td>21.8</td>
</tr>
<tr>
<td>ND457-1</td>
<td>26.2</td>
<td>26.5</td>
</tr>
<tr>
<td>X96-56</td>
<td>21.1</td>
<td>21.6</td>
</tr>
<tr>
<td>B3131-8</td>
<td>20.6</td>
<td>21.4</td>
</tr>
</tbody>
</table>
DISCUSSION

The line and tester clones used in this study originally were selected from \( F_1 \) crosses of heterozygous parents. Each clone had been tested for several years and retained because of one or more desirable attributes. Within this experimental population, there was no evidence of planned inbreeding. Therefore, it is assumed that the clones tested in the present study represent highly heterozygous parents. It is further assumed that this population is a representative sample of the genes found in clones used in the United States.

In efforts to determine the type of gene action present in a crop, it is of considerable importance to ascertain the population to which the results might apply. The information obtained concerning gene action in this study was felt to be relative to comparable populations of lines derived from American potato breeding programs. This reasoning assumes that the lines and testers comprise a diverse sample from a number of breeding programs.

Potato breeders have long recognized that it is extremely difficult to predict the results of a given cross. This has been especially true for yield and such characters influenced by environmental fluctuation. Most breeders have concluded that specific combining ability is more important than general combining ability in the potato for such quantitative characters. This conclusion is the result of observations made in practical breeding programs and not from specific studies to determine gene action. These potato
breeders also consider the technique of recurrent selection to have potential as a method to increase the efficiency of potato improvement. Before such a method is used, however, the relative importance of additive and non-additive effects should be ascertained. This information has been obtained for a number of crops, such as corn, and has been helpful in developing new breeding techniques.

One of the purposes of this study was to obtain estimates of general and specific combining ability in $F_1$ crosses of potato clones. General combining ability is largely a result of additive effects, whereas specific combining ability is a combination of dominance, epistasis, and other genetic interactions.

The results of this study tend to verify the importance of specific combining ability for yield. In the analysis for line, tester, and line x tester components, the line and tester values are analogous to general combining ability, or the average effect of lines and testers. The line x tester variance component is similar to specific combining ability in that it is a measure of the variability of specific crosses of lines and testers.

These analyses show similar results for yield at each of the three locations. The line x tester component was consistently larger than the line and tester components. This difference was most noticeable at Ithaca, New York. Smaller differences were found in the data from Riverhead and Clear Lake. These data suggest that specific combining ability is of primary importance in determining yield as measured over widely differing environments. This evidence
is in general agreement with that of Sprague and Tatum (42). In previously tested and selected corn lines, these authors reported that specific combining ability was more important than general combining ability. In the present study, it is felt that the importance of specific combining ability also can be related to the tetraploid inheritance of potatoes and to the heterozygous nature of the parental clones.

In the combined-location analysis for yield, the estimate of specific combining ability x location \( (\sigma^2_1)_{xt} \) x \( p \) was approximately 12 times that of general combining ability x location \( (\sigma^2_1)_{xp} \) and \( (\sigma^2_1)_{tp} \). This result agrees with Rojas and Sprague (41) who reported that estimates of specific combining ability in corn tend to interact more with environment than do estimates of general combining ability.

From the comparison of tester means over lines, it appears that there is no difference in general combining ability for yield. Tester TL1859 gave the largest relative effect in determining yield at each location. This relative effect assumes that there is no interaction between lines and testers. Although a sizeable interaction was shown, it is felt that the relative effect values are indicative of the performance of testers. It would seem that the effect of tester TL1859 must be mostly specific in nature. A possible explanation for the predominance of specific combining ability is the close relationship between this tester and the lines with which it was crossed. Grogan and Zuber (14) and Keller (25a) found in corn that testers closely related to the inbred lines would not give an accurate estimate of the general combining ability of the lines because of the apparent
increases in specific effects. In the present study, simple comparisons between related and unrelated crosses within each tester revealed no substantial differences, and would suggest that the existence of a relationship between testers and lines in potatoes has little effect on combining ability for yield. However, differences could exist in general and specific combining ability of related and unrelated material which might have been averaged out in such a comparison. The evidence in this study can be considered only as preliminary in an area where further study is needed.

The estimates for specific gravity of the \( \sigma^2_l \), \( \sigma^2_t \), and \( \sigma^2_{lt} \) components reveal that general combining ability was more important than specific combining ability. The line and tester components were twice that of the line x tester component. This result coincides with observations of potato breeders after making crosses between clones of high specific gravity. In general, a large number of plants with high specific gravity can be found in progenies from crosses between parents of high specific gravity. The genes that affect specific gravity apparently are fewer in number than those affecting yielding ability. These data further indicate that gene effects are largely additive.

Comparisons among means of testers for specific gravity reveal a significant difference between the largest mean, B962-32, and two of the low means, Katahdin and TL1859. This indicates that B962-32 is superior as a general combiner. No other differences in the general combining ability of the testers could be detected.
It is of interest to note that the testers which are considered to have high specific gravity (B962-32, B3131-8, and ND457-1) had the highest relative effects for determining specific gravity. Those with relatively low specific gravity (Katahdin, TL1859, and X96-56) had the lowest effects. These data seem to indicate that the specific gravity phenotype of a parent gives a fair prediction of performance of its progeny in $F_1$ crosses.

The results of the analysis to determine general and specific combining ability for tuber appearance suggest a lack of predominance of either. A comparison of tester means over lines revealed that ND457-1 is a significantly better general combiner than the other five. The data for relative tester effects showed that the two testers, ND457-1 and Katahdin, which have been particularly noted for imparting desirable tuber appearance to their progeny, had the largest effects.

It is the present goal of many potato breeders to develop parental material of superior general combining ability for particular characteristics such as high yield, disease resistance, and high specific gravity. Efficient progress towards such a goal can be realized only if the character shows a predominance of additive genetic variance. The present study indicates that it may be difficult to obtain clones homozygous for general combining ability for yield. This conclusion is supported by the predominant non-additive effects found for yield in evaluating six testers. Selection for additive effects would appear to require a large number of testers.
in order that the specific effects of each tester could be averaged out. Information concerning the number of testers required for measurable genetic advance could not be adequately obtained in this experiment and is an area for further study. The data from this experiment indicate that specific effects in the potato react more to various environments than general effects. This observation suggests that progeny tests for yield should be conducted for more than one year and in more than one location.

Because of the relative importance of additive effects, it would seem possible to develop parental clones of good general combining ability for specific gravity. A substantial variance for additive gene action was found for this character. The number of testers needed would tend to be less than that required for evaluating yield. Since additive and non-additive genetic variances were found to be of equal importance for tuber appearance, it should be possible to develop good combiners for this character without recourse to large numbers of testers.

Data presented by Matzinger (33), Rojas and Sprague (41), and Federer and Sprague (9) have indicated that genetic responses are generally affected by the particular year and location in which the tests are grown. For this reason, these authors have suggested that tests be conducted in a number of locations and for more than one year. Data obtained in several environments increase the reliability of the results. Since this experiment includes data of but one year and is the first attempt to estimate gene action in a population
of potato clones, the importance of additive and non-additive effects shown for the characters studied should be considered only as indications of possible genetic patterns. However, it is felt that the information obtained for yield is more reliable than that obtained for specific gravity or tuber appearance. This reliability is based upon the three locations from which yield data was obtained. These locations differed widely in soil type, light intensity, and other environmental forces. Further work, however, would undoubtedly be helpful in defining more precisely the effect of gene action in a potato breeding program.
SUMMARY

This study was designed to obtain estimates of general and specific combining ability variances from tests of 190 F<sub>1</sub> crosses and to evaluate six proposed tester clones for total yield, specific gravity, and tuber appearance.

Crosses were made between 45 diverse breeding lines and six clones selected as testers. The 190 crosses obtained were tested at Ithaca and Riverhead, New York, and at Clear Lake, Iowa, in a modified rectangular lattice design. Total yield data were taken at all locations. Specific gravity and tuber appearance measurements were recorded only at the Clear Lake location.

The calculation of line, tester, and line x tester variance components indicated that specific combining ability was relatively more important than general combining ability for yield. No substantial differences in the general combining ability of testers could be found in comparing their means. Significant interaction of specific combining ability with locations was observed in these data. Calculation of relative effects of each tester revealed that tester TL1859 was consistently high in all locations. It was concluded that its effect was largely non-additive. These yield data indicate that genetic improvement for this character would be difficult. A large number of testers would be required to select from the relatively small additive effects found.

General combining ability was found to be more important than
specific combining ability in determining specific gravity. Tester B962-32 was significantly superior in mean performance to the two poorest testers. Testers B962-32, ND457-1, and B3131-8 gave the largest relative effects. Each of these clones is of high specific gravity. The three low specific gravity testers gave relatively small effects. It was therefore concluded that the phenotypic response of a parent for specific gravity would give fair prediction of its progenies performance. The data suggested that good general combining clones could be obtained through recurrent selection for additive effects.

General and specific combining ability were found to be of equal importance in determining tuber appearance. Tester ND457-1 was found superior as a general combiner. This tester and Katahdin gave the largest relative effects. These results agree with previous observation of the excellence of both clones as parents. It was felt that additive variation for tuber appearance is of sufficient magnitude to realize substantial genetic progress through development of clones of high general combining ability.

Comparisons of crosses between related, and unrelated lines and testers indicated that the relationship between testers and lines apparently has little or no effect on the resulting progeny. It was pointed out, however, that differences could have been averaged out by specific effects in such comparisons.
LITERATURE CITED


ACKNOWLEDGMENTS

The author wishes to express special appreciation to the following individuals who assisted in this study:

His major professors, Dr. A. E. Kehr under whose guidance the investigation was inaugurated and Dr. E. S. Haber, who assisted in bringing it to a conclusion;

Dr. L. C. Peirce for invaluable help in the preparation of the manuscript;

Professor Oscar Kempthorne and Mr. Neeti Bohidar for assistance in the statistical analysis of the study; and

Dr. R. L. Plaisted for his co-operation and assistance during the entire study.