A COMPARATIVE STUDY OF THE SEASONAL ROOT DEVELOPMENT OF SOME INBRED LINES AND HYBRIDS OF MAIZE

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INTRODUCTION

In an endeavor to gain further knowledge of the root system of corn (Zea mays L.), an investigation was planned to include both the developmental and genetic aspects. Some of the primary objectives were as follows: (1) To obtain a detailed record of the growth of the root system of corn from planting to maturity; (2) to determine the range in root characters among certain inbred lines; (3) to ascertain how these root characters are expressed in hybrid combinations; and (4) to identify any characters possibly associated with the force required to pull a corn plant from the ground.

HISTORICAL REVIEW

Pavlychenko (16) recently published an excellent review of the various methods employed in the past in the study of root systems. In addition to his own "soil-block" washing method, he described 11 different procedures used by previous investigators, viz, direct washing, trench washing, steel-frame washing, soil-prism washing, concrete-compartment washing, nail-and-needle-brush washing, Hellriegel's steel cylinder, water-culture and soil containers, observation pit, direct tracing, and Weaver's trench method. Sayre used the "lithium" method to determine the extent of corn root systems. After lithium had been placed in the soil at definite distances from the plant, the stalk was tested for its presence. By this means he hoped to determine the lateral extension of the root system. The results, however, failed to agree with observations made by the direct tracing of the roots. Sayre suggested that his results may more nearly represent the absorptive area of the corn root system than the maximum extension of some of the individual roots.

The majority of the investigations relating to the roots of corn have been primarily concerned with the distribution of the roots in the soil. The reports vary widely as to the extension of the root system vertically and horizontally. Hickman (7), in Pennsylvania, and Farris (3), in New Jersey, found that the root system was relatively shallow. The maximum distance of penetration in New Jersey was only 2 feet,
both laterally and vertically. Other reports on the distribution of the roots of corn have come from Morrow and Hunt (15), in Illinois, Hays (6), in Minnesota, King (11), in Wisconsin, Ten Eyck (24, pp. 333–346; 25), in North Dakota and Kansas, Shepperd (20, pp. 529–555), in North Dakota, Miller (14), in Kansas, and Weaver et al. (26, 27), in Nebraska. This group of investigators found corn roots at depths ranging from 4 to 8 feet and with lateral extensions ranging from 2 to 4 feet. In all cases the corn root system extended to considerably greater distances than those reported from Pennsylvania and New Jersey. Several of these workers noted that the crown roots from the lower nodes extended almost horizontally from the culm, whereas the roots from the higher nodes often extended nearly vertically into the soil.

Less attention has been devoted to the seasonal development of the root system of corn than to the distribution in the soil of the roots of a mature plant. Hickman (7) obtained measurements of the size of the root systems at 2, 4, 6, and 8 weeks after planting. In general, his observations during this period of growth agree with those in the present study. Weihing (28) examined corn roots 2, 4, 6, 8, and 12 weeks after planting, both in pots and in the field. Rotmistrov (18) found that from the “bushing” to the flowering period maize roots averaged a daily growth of 1.5 cm. vertically and 0.8 cm. horizontally. Bensin (1), in Czechoslovakia, observed that the maximum extension of the roots was reached at the time of tasseling.

In connection with the lodging of corn, the study of the root system has naturally assumed some importance. Holbert and Koehler (8) designed a plant-pulling machine to determine the force required to pull a plant from the ground. Koehler, Dungan, and Holbert (12) observed that an inbred strain of corn with the ability to stand erect possessed a root system about twice as large as that of a strain inclined to lodge. Hayes and McClelland (5) found that—

* * * where parents (inbred lines) were widely different in ability to withstand lodging, the F1 was, in general, of intermediate habit, although there were some exceptions to this rule. When both parents had low lodging indices, the F1 crosses were also low and when both parents had high lodging indices, the F1 crosses lodged severely, as a rule.

Wilson (30) noted that the presence of many brace roots and short distances between the lower nodes of the corn plant were important in the prevention of lodging. Pettinger (17) found that potassium and phosphorus were especially beneficial in promoting strong root growth. The weather, however, was found to be a more important factor in the determination of lodging than either the fertilizers or the cropping systems employed. Hall (4, p. 26) observed that lodging was determined by a complex of morphological factors and—

* * * that strong lines were strong because they possessed one or more characters that correlate highly with erect plants and in spite of the fact that they also possessed certain characters that might be associated with weak lines.

Literature relating to purely genetical studies of root characters is scarce. The only gene definitely identified in connection with a root character of corn has been described by Jenkins (9). Plants exhibiting the effects of this gene have fewer primary (or main) roots than has ordinary corn. Kiesselbach and Weihing (10), studying mature plants, noted the comparative root development of selfed lines of corn
and their F₁ and F₂ hybrids. Hybridization markedly stimulated the penetration, spread, length, and diameter of the roots in the first generation, whereas those of the second generation were intermediate in these respects. Smith (23) noted that a high ratio of secondary roots to primary roots was the rule in "phosphate efficient" lines and that in the F₁ a high ratio of secondary to primary roots was dominant over a low ratio.

Some attention has been given to the seminal root system of corn. Wiggans (29) reported that dent corn and popcorn usually have four "temporary" roots (including the radicle). Flint and sweet corns usually have only one temporary root, the radicle. Siemens' (21) results were similar to those of Wiggans, except that he found Michigan popcorn among those types that have no secondary seminal roots. Smith and Walworth (22) believed they had accumulated rather strong evidence for a significant positive correlation between yield and seminal root development, but Collins (2) advanced certain criticisms against their methods. Mangelsdorf and Goodsell (13) failed to find a correlation between seminal root development and yield in four out of five tests.

MATERIALS AND METHODS

The strains selected for the root studies consisted of four inbred lines, 56, 4-8, 51, and 84; two single-cross hybrids, 56 X 4-8 and 51 X 84; and one double-cross hybrid, (56 X 4-8) X (51 X 84). The four inbred lines are at present being widely used in Ohio in the commercial production of hybrid seed corn. Line 56 matures at about the average date at Wooster, Ohio, line 4-8 later than average, and lines 51 and 84 approximately 10 days earlier than average.

The planting was made in the spring of 1937 at the Ohio Agricultural Experiment Station at Wooster as part of the regular farm rotation of corn-oats-wheat-alfalfa. The soil type, Wooster silt loam, is derived from sandstone and shale, glaciated, and naturally well drained.

The average monthly precipitation and temperature during the 1937 season at Wooster closely approximated the 40-year average.

The planting was arranged in four replications of three-row plots. The individual plants were separated by a minimum distance of 40 inches.

The planting was made on May 27, and the first root samples were obtained 16 days later. The samples consisted of five root systems of each strain, and they were taken at random on the same day of each succeeding week until 15 weeks after planting. The root systems were removed from the ground in a cylinder of soil 16 inches in diameter and 10 inches in depth, securely wrapped with burlap, and thoroughly soaked prior to removal of the soil with a fine spray of water. Practically no rootlets were lost by this washing process. Obviously, a cylinder of soil of these dimensions did not include the entire root system, but direct tracings of the roots by the trench method indicated that the great bulk of the root system, including practically all of the fibrous portions, was obtained.

Direct tracing of the crown roots, by the trench method, was accomplished for one plant of each strain at three times during the season.
THE SEMINAL ROOT SYSTEM

DRY WEIGHT, COMBINED LENGTH, AND NUMBER OF SEMINAL ROOTS

Table 1 gives the mean values obtained for the measurements of the seminal roots of the inbred lines and hybrids from the second to the seventh week after planting. The dry weights of the roots of the inbred lines reached a maximum at about the fourth week and those of the hybrids at about the fifth week, after which time their dry weights decreased. At 3 weeks, the first internode of many of the plants began to show severe rot injury. With the partial or complete death of the tissues in this region, it is doubtful whether the seminal root system was any longer active in absorption. At least 5 weeks before the crown root systems reached their maximum growth, the seminal root systems were entirely dead. It is believed that this premature death of the seminal roots was due entirely to the many injurious insects and fungi present in the field soil.

### Table 1.—Average weight, length, and number of seminal roots per plant in the inbred lines and hybrids from the second to the seventh week after planting

<table>
<thead>
<tr>
<th>Inbred line or hybrid</th>
<th>Average values for seminal roots per plant from the second to the seventh week after planting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry weight</td>
</tr>
<tr>
<td>Inbred lines:</td>
<td>Gram</td>
</tr>
<tr>
<td>56</td>
<td>.062</td>
</tr>
<tr>
<td>4-8</td>
<td>.080</td>
</tr>
<tr>
<td>51</td>
<td>.085</td>
</tr>
<tr>
<td>84</td>
<td>.053</td>
</tr>
<tr>
<td>Minimum significant difference ².</td>
<td>0.020</td>
</tr>
</tbody>
</table>

| Hybrids:              |                               |                               |
| 56 × 4-8.             | .143                            | 73.7                            | 4.7     |
| 51 × 84.              | .133                            | 64.0                            | 4.3     |
| (56 × 4-8) × (51 × 84) | .155                            | 67.9                            | 4.3     |
| Minimum significant difference ². | .038    | 10.9         | .41     |

¹ Including the radicle.
² Minimum difference for significance calculated as twice the standard error of a difference.

Even 16 days after planting, the seminal roots of the hybrids exhibited marked hybrid vigor, in contrast to the roots of the inbred lines. This was apparent in the fact that the hybrids had a greater number of roots, with a greater dry weight and combined length. The hybrids showed significant differences only in respect to number of roots, whereas the inbred lines showed significant differences in number and dry weight (table 1). Consequently, the differences between the seminal roots of the inbred lines were reflected between the hybrids only in respect to the number of roots.

It was of interest to note in what degree the seminal root development of the various strains correlated with the development of the crown roots and the shoot. Within neither group of strains was it possible to predict the relative number of crown roots from the number of seminal roots, nor was it possible to predict the relative dry weight of the crown roots from the dry weight of the seminal roots. Likewise, the information on the number or the dry weight of the
DISTRIBUTION OF SEMINAL ROOTS IN THE SOIL

The direct tracing study by the trench method at 30 days after planting indicated a predominantly horizontal distribution of both the radicle and the secondary seminal roots. Maximum distances of penetration observed for the radicle were 4 inches vertically and 7 inches horizontally. The secondary seminal roots occupied a position similar to that of the radicle.

THE CROWN ROOT SYSTEM

COMPARATIVE DEVELOPMENT OF CROWN AND SEMINAL ROOTS

The crown roots began a rapid growth soon after germination and in a short time far surpassed the seminal roots in dry weight. At 3 weeks after planting, the crown and seminal roots were about equal in dry weight. At only 6 weeks after planting, the crown roots were at least 25 times as heavy as the seminal roots, and for one strain the ratio was as great as 55 to 1.

The increase in the dry weight of the crown roots of both the inbred lines and the hybrids is illustrated graphically in figure 1, A. The data form a typical S-shaped growth curve. Distinct differences in dry weight could be observed at 16 days after planting, and at 15 weeks most of the strains were widely separated. When fully developed the largest root system (56 × 4–8) was twice the dry weight of the root system of the largest inbred line (4–8) and four times that of the root system of the smallest inbred line (51). The ratio of the dry weights of the roots between the two groups of strains, however, remained at a value of about 2 or 3 during most of the season.

The maximum dry weight of the crown roots was attained at approximately the time of silking for the majority of the strains. There was some indication that the maximum dry weight was attained the week following silking for two of the strains. Larger samples of each strain would be required to ascertain this point with greater accuracy.

The maximum dry weight of roots attained by a particular inbred line was related in some degree to its time of maturity. For example, line 4–8 was the latest of the lines to mature and had the greatest dry weight of roots. Line 51 was the earliest and had the least dry weight of roots. Line 84, however, was nearly as early as line 51 but had a considerably greater dry weight of roots. It would, therefore, seem that at least among the inbred lines certain hereditary factors other than time of maturity influenced the maximum dry weight of the crown roots. Among the hybrids the maximum dry weight of roots increased in the order of the lateness of maturity of the strains.

Differences in dry weight of roots among the inbred lines were reflected in the differences among the hybrids. The double-cross hybrid had a root weight somewhat intermediate between the single-cross hybrids, but, as in many other root characters, it most nearly resembled the single cross 56 × 4–8.
A differential seasonal response seems to occur among the four inbred lines, as indicated by the dry weights of roots at 10 weeks and 13 weeks after planting (fig. 1, B). On this basis lines 84 and 4–8 should resist lodging best, followed by lines 56 and 51. At 13 weeks after planting the expected order would be: 4–8, 56, 84, and 51. No data are available to test the differential seasonal root development as a criterion of the ability of a plant to resist lodging, but the problem is of sufficient importance to deserve further study. An examination

![Figure 1](image-url)
of the growth curves of the dry weights of roots of the hybrids shows that they differed little in dry weight up to 9 weeks after planting but that the differences increased after that time. Consequently, the possibility of a differential seasonal response with respect to lodging is likewise suggested for the hybrids.

TOTAL LENGTH OF MAIN ROOTS OF CROWN ROOT SYSTEMS DURING THE GROWING SEASON

The seven strains of corn differed in several root characters in addition to dry weight. Table 2 gives the mean total length of the main roots of the crown root systems for two different periods during the growing season. Obviously, the hybrids had a considerably greater total length of main roots than did the inbred lines. Within each group of strains, the differences are not so pronounced as they were in regard to dry weight. Line 51, for example, is the only one of the inbred lines differing significantly from the other lines in the total length of the main roots of the mature root systems. The total length of the main roots of the hybrids reflects a situation closely resembling that for dry weight of roots. The single crosses differed significantly in total length of the main roots of the mature root systems, but the double-cross hybrid differed significantly only from cross 51 × 84.

<table>
<thead>
<tr>
<th>Inbred line or hybrid</th>
<th>Mean total length per plant of main roots of crown root systems for period indicated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Second to ninth week, inclusive</td>
</tr>
<tr>
<td></td>
<td>Centimeters</td>
</tr>
<tr>
<td>Inbred lines:</td>
<td>384.7</td>
</tr>
<tr>
<td>56</td>
<td>395.0</td>
</tr>
<tr>
<td>4-8</td>
<td>395.0</td>
</tr>
<tr>
<td>51</td>
<td>374.6</td>
</tr>
<tr>
<td>84</td>
<td>59.96</td>
</tr>
<tr>
<td>Minimum significant difference</td>
<td>59.96</td>
</tr>
<tr>
<td>Hybrids:</td>
<td>59.96</td>
</tr>
<tr>
<td>56 × 4-8</td>
<td>55.60</td>
</tr>
<tr>
<td>51 × 84</td>
<td>55.60</td>
</tr>
<tr>
<td>(56 × 4-8) × (51 × 84)</td>
<td>55.60</td>
</tr>
<tr>
<td>Minimum significant difference</td>
<td>55.60</td>
</tr>
</tbody>
</table>

1 Beginning with the tenth week, length measurements were not taken on the roots of the lower three nodes because of the injury which they suffered from insects and root rot.
2 Minimum difference for significance calculated as twice the standard error of a difference.

NUMBER OF "FUNCTIONAL" MAIN ROOTS DURING THE GROWING SEASON

Roots which entered the soil were arbitrarily termed "functional." The root systems of the hybrids exceeded those of the inbred lines by a considerable margin both in dry weight and total length of the main roots, but this was not true with respect to the number of functional main roots (fig. 2). For this latter character, the root system of one inbred line (4–8), when fully developed, exceeded that of any of the hybrids. The root systems of the hybrids, however, had more main roots than the remaining inbred lines. The hybrids
showed only small differences in this character, but again 56 × 4–8 and the double-cross hybrid were more nearly alike than were 51 × 84 and the double cross. Each single cross more nearly resembled the inbred parent having the larger number of main roots than it did the inbred parent having the smaller number of main roots.

Differences in the number of functional main roots were evident at 16 days after planting and remained fairly consistent during the growing season. The mean number of main roots among all the strains ranged from 5.5 to 7.7 at 16 days and from 50.0 to 79.2 at 15 weeks. This root character, like dry weight and total length of main roots, reached a maximum value at or slightly subsequent to the time of silking.
ROOT DEVELOPMENT AT DIFFERENT NODES

CHARACTERISTICS OF CROWN ROOTS AT EACH NODE

The crown root system of corn develops by successively higher whorls of roots at closely set nodes. Theoretically, the scutellar node is the lowest node of the plant, but for practical purposes, the lowest node that gave rise to a whorl of crown roots was designated as the first node in this study. Successively higher nodes with whorls of crown roots were numbered in the order of their occurrence. Despite the proximity of these lower nodes, they are nearly always distinguishable, and rarely is any difficulty encountered in determining their exact sequence. The number of main roots per node increases rather slowly upward to the third or fourth node and then more rapidly at the nodes higher on the culm. A typical sequence of number of main roots for a mature plant of $56 \times 4-8$ from the first to the tenth node was as follows: 4, 4, 4, 4, 5, 7, 9, 12, 16, 13.

![Root systems of inbred lines and hybrids of maize 2 weeks after planting](image)

The main roots arising from the first three or four nodes were of a relatively small and uniform diameter throughout their length (fig. 3). These roots early develop an extensive growth of fine lateral rootlets. As the main roots from each higher node appear, there is a progressive increase in diameter, but this thickness is not maintained throughout their length. The earliest and most vigorous growth of lateral rootlets occurs proximally unless the main root sustains severe injury from some source. In that event, dependent upon the strain of corn concerned, the most vigorous growth of lateral rootlets may occur just proximal to the point of injury.

Probably one of the most significant facts revealed in this root study is that strains of corn differ tremendously both in the ordinary production of lateral rootlets and in their production subsequent to the severance of the main root by some insect pests. Two of the in-
bred lines employed in this study, 4–8 and 51, had a small number of lateral rootlets and the other two lines, 56 and 84, were plentifully supplied with them. These differences are readily seen in figure 4. Such variations in root growth must mean very great differences in the total area of root surface in contact with soil particles, and, consequently, may be an important factor in soil, air, water, and nutrient relationships with the plant. The fact that the inbred lines show a differential response in lateral root growth following insect injury may be of importance in areas where corn is damaged as a result of the activities of such insect pests as the southern corn rootworm.
NUMBER OF WHORLS OF "FUNCTIONAL" CROWN ROOTS DURING THE GROWING SEASON

At 16 days after planting the number of whorls of crown roots (fig. 5) ranged from 1.7 to 2.0, and at 15 weeks after planting they ranged from 8.0 to 10.4. In general, during the 1937 season about one additional whorl of roots developed each week for the first 8 or 9 weeks after planting.
In total number of nodes with roots, one of the inbred lines (56) again exceeded any of the hybrids. The fully developed root system of this line had slightly more than 10 nodes with roots, whereas the most poorly developed inbred line (51) had only 8 nodes. The single-cross hybrids exhibited a significant difference of nearly 1 whole node with roots in their fully developed root systems. One single-cross hybrid (56 × 4-8) most closely resembled the inbred line 4-8 with the smaller number of nodes with roots, whereas the other single-cross hybrid (51 × 84) seemed to be about intermediate to its component inbred lines in this root character. The single-cross 56 × 4-8 and the double-cross hybrid failed to differ significantly in the maximum number of nodes with roots.

TOP-TO-ROOT RATIOS DURING THE GROWING SEASON

At 16 days after planting, the top was one to two times heavier than the root system (fig. 6). Throughout the season this disproportion between the dry weights became constantly greater until 15 weeks after planting, when the top-to-root ratio was more than 20:1 for some of the strains. The ratios for the single-cross hybrids were approximately intermediate between the ratios of their inbred parents up to the time of silking, when the hybrid ratios tended to equal or exceed those of the inbred parent with the larger ratio. The double-cross hybrid exhibited a higher ratio than either of the single-cross hybrids up to 9 weeks after planting. Its ratio then became intermediate between the two single-cross ratios and finally appeared to be nearly identical with that of cross 56 × 4-8.

Several investigators have reported on the top-to-root ratio of corn at various periods during the growing season. Hickman (7), in Pennsylvania, found the ratio to be 0.6:1 for plants 2 weeks old and 3.2:1 for plants 4 weeks old. The corresponding average values for the hybrids in this study were 1.4:1 and 2.7:1. King (11, Rpt. 9), in Wisconsin, reported the ratio at maturity to be 6.7:1. Miller (14), in Kansas, found the ratio at maturity to average 9.6:1 in 1914 and 7.8:1 in 1915. Schweitzer (19), in Missouri, reported the ratio to be 23.7:1 on September 10. Weihing (28), in Nebraska, found the ratio to be 6.4:1 for a small variety grown to maturity in pots. Rotmistrov (18, p. 51) reduced the relationship to a general law by stating that—

* * * at the beginning of the development the weight of the roots exceeds the weight of the superficial parts, in the middle part of the development, the relation approximates 1:1, and at the end of the development the weight of the superficial parts exceeds that of the roots.

This law did not seem applicable to the strains of corn included in this study, since even at 2 weeks after planting the top in all cases outweighed the roots.

In general, the top-to-root ratios of the strains in this study exceeded the ratios reported in previous studies. At 15 weeks after planting, the smallest ratio was 12:1 and the largest 23:1.
Figure 6.—Top-to-root ratios, based on the dry weights, of inbred lines and hybrids of maize from the second to the fifteenth week after planting. W17 is the double-cross hybrid \((56 \times 4-8) \times (51 \times 84)\). Curves smoothed by computing a moving average of 3 weeks' data.
DISTRIBUTION OF MAIN ROOTS OF CROWN ROOT SYSTEMS IN THE SOIL DURING THE GROWING SEASON

The main roots of the crown root systems were traced for one plant of each strain at 30, 49, and 87 days after planting. The trench method was employed in making the excavations.

At 30 days after planting, the main roots of the inbred lines had not quite penetrated halfway through the 7 to 12 inches of surface soil. Both the crown roots and the seminal roots extended nearly horizontally from the culm. The maximum lateral spread observed was 12 inches. No marked difference was evident between the inbred lines and the hybrids at this period either in the depth of penetration or in the lateral spread.

At 49 days after planting, most of the roots of the inbred lines had penetrated to a maximum depth of 10 to 12 inches and extended laterally to slightly greater distances. Line 51 had a root system that was markedly restricted in distribution. The roots of the hybrids seemed to be somewhat more extensively distributed at this period than the roots of the inbred lines. Maximum distances of penetration were 2 feet both horizontally and vertically.

The last examination of the root systems was made 87 days after planting. There seemed to be no significant changes in maximum values for the depth and lateral extension of the main roots since the 49-day examination.

It is apparent that the root system of corn extended to relatively short distances at Wooster during the 1937 season. The results agree with those obtained by Hickman (7), in Pennsylvania, and Farris (3), in New Jersey. The studies of King (11), Shepperd (20), Miller (14), and Weaver (26) in Wisconsin, North Dakota, Kansas, and Nebraska, respectively, indicate, however, that under certain soil and climatic conditions corn may be much more deeply rooted.

PULLING RESISTANCE AND SOME ASSOCIATED ROOT CHARACTERS

A plant-pulling machine was used to determine the force required to pull a single root system from the ground. This machine was equipped with a single movable pulley operating between the scales and a stalk attachment device. Twenty plants of each strain were pulled on August 14, 11 weeks after planting.

All the hybrids surpassed the inbred lines in mean pulling resistance (table 3). The pulling resistance of the lines ranged from 158 pounds to 227 pounds and that of the hybrids from 290 pounds to 350 pounds. The low value for line 51 was expected on the basis of its poorly developed root system. The double-cross hybrid was nearly identical with the single-cross hybrid 56 × 4–8 in pulling resistance.

Mean values for some of the characters that might have been influential in promoting strong rooting are given in table 3. Correlation coefficients were calculated within strains between (1) pulling resistance and dry weight of the crown root system and (2) pulling resistance and the number of main roots (table 4). Significant positive correlations within five strains were found between pulling resistance and root weight. No significant correlations were evident between pulling resistance and number of main roots.
### Table 3.—Mean pulling resistance and mean values for some associated root characters in the inbred lines and hybrids of maize

<table>
<thead>
<tr>
<th>Inbred line or hybrid</th>
<th>Pulling resistance</th>
<th>Dry weight of crown roots</th>
<th>Crown roots</th>
<th>Nodes with roots</th>
<th>Vertical distance on culm with functional roots</th>
<th>Above-ground nodes with functional roots</th>
<th>Diam. of culm</th>
<th>Diam. of roots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inbred lines:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>227</td>
<td>13.1</td>
<td>60.1</td>
<td>10.1</td>
<td>174</td>
<td>7.6</td>
<td>1.2</td>
<td>2.22</td>
</tr>
<tr>
<td>4-8</td>
<td>209</td>
<td>17.4</td>
<td>78.0</td>
<td>9.3</td>
<td>200</td>
<td>7.8</td>
<td>1.2</td>
<td>2.45</td>
</tr>
<tr>
<td>51</td>
<td>158</td>
<td>8.9</td>
<td>53.6</td>
<td>8.1</td>
<td>197</td>
<td>4.7</td>
<td>1.7</td>
<td>2.10</td>
</tr>
<tr>
<td>84</td>
<td>188</td>
<td>13.4</td>
<td>66.3</td>
<td>9.2</td>
<td>141</td>
<td>4.8</td>
<td>1.1</td>
<td>2.02</td>
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<tr>
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<td><strong>1.3</strong></td>
<td><strong>4.4</strong></td>
<td><strong>3</strong></td>
<td><strong>6.0</strong></td>
<td><strong>.9</strong></td>
<td><strong>3</strong></td>
<td><strong>.13</strong></td>
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<tr>
<td>Hybrids:</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>56 X 4-8</td>
<td>350</td>
<td>32.0</td>
<td>72.1</td>
<td>9.4</td>
<td>264</td>
<td>8.9</td>
<td>1.7</td>
<td>2.92</td>
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<tr>
<td>51 X 84</td>
<td>290</td>
<td>23.3</td>
<td>67.5</td>
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<td>5.3</td>
<td>1.0</td>
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</tr>
<tr>
<td>(56 X 4-8) X (51 X 84)</td>
<td>333</td>
<td>30.0</td>
<td>72.8</td>
<td>9.1</td>
<td>263</td>
<td>7.1</td>
<td>1.3</td>
<td>2.83</td>
</tr>
<tr>
<td><strong>Minimum significant difference</strong></td>
<td><strong>51.0</strong></td>
<td><strong>3.3</strong></td>
<td><strong>4.8</strong></td>
<td><strong>.4</strong></td>
<td><strong>5.0</strong></td>
<td><strong>1.4</strong></td>
<td><strong>3</strong></td>
<td><strong>.12</strong></td>
</tr>
</tbody>
</table>

1 Mean values obtained from samples taken from weeks 12 to 15.
2 Measured to the tip of the tallest leaf when stretched vertically.

Dry weight of roots was closely associated with pulling resistance (table 3). The only other root character that appeared to be related to pulling resistance among both inbred lines and hybrids was root diameter. Among the inbred lines as a group and the hybrids as a group, the vertical distance on the culm with "functional" roots seemed to bear a relation to pulling resistance. A similar situation existed in regard to the number of nodes with roots. Pulling resistance seemed to be more closely related to the number of above-ground nodes with functional roots among the hybrids than among the inbred lines. Plant height and culm diameter seemed to bear little rela-
tion to pulling resistance among the lines, but among the hybrids the tallest plants with the thickest culms had the greatest pulling resistance.

There was hardly sufficient lodging in the plots during the 1937 season to establish any marked differences among the strains. In lines 56, 4–8, 51, and 84, respectively, 5.5, 2.6, 37.1, and 2.2 percent of the plants lodged at an angle of 45° or greater in November. In hybrids 56×4–8 and 51×84 and the double-cross hybrid, respectively, 0.3, 2.1, and 1.9 percent of the plants lodged. Line 51 failed to remain erect even in a season unfavorable to lodging. This might have been predicted on the basis of its extremely poor root development.

**SUMMARY**

A comparative study was made of the seasonal development of the corn root system by the use of a double-cross hybrid, two single-cross hybrids, and the four inbred lines employed in making up the hybrids.

The seminal root systems of the hybrids were larger than those of the inbred lines, but in both groups of strains they died early in the growing season, probably because of injuries sustained from various insect larvae and root diseases. There was no consistent correlation, within either group of strains, between the development of the seminal roots and the development of the crown roots or the tops.

Marked differences were noted among the strains in regard to number, dry weight, and total length of the main roots of the corn root systems. The graph of total dry weight of the roots determined at weekly intervals followed a typical S-shaped growth curve. The maximum dry weight of the crown roots was reached at approximately the silking stage in five of the strains and possibly the week following silking for the remaining two strains. It was believed that the inbred lines and hybrids might be expected to show relatively different degrees of resistance to lodging at successive stages of growth on the basis of the growth curves of their roots.

Striking differences were noted among the inbred lines in the ordinary development of lateral roots and in the amount of stimulated lateral root growth following injury of a main root by soil insects.

The top-to-root ratio was nearly 2:1 for some strains at 2 weeks after planting but varied from 12:1 to 23:1 among the strains at 15 weeks after planting. There was no close correlation among the inbred lines between the dry weights of the tops and of the roots.

The single-cross hybrids exceeded the inbred lines in dry weight of roots, dry weight of tops, diameter of main roots, length of roots, resistance to a vertical pull, diameter of culm, and plant height; they tended to approximate the inbred line with the greater number of main roots, but no consistent relation was evident with respect to the number of nodes with roots; they were intermediate between their constituent lines in the top to root ratio during most of the growing season. The double-cross hybrid and one of the single crosses (56×4–8) were nearly identical with respect to most of the root characters studied.

In the plants studied, about one additional whorl of crown roots was developed during each week of the first 8 or 9 weeks of the growing season.
The root systems of both the inbred lines and the hybrids were exceedingly shallow as compared with those reported from the prairie regions of the United States. Data are given for the distribution of the main roots at three different periods during the growing season.

Within all strains the number of pounds required to pull a corn plant from the ground was most closely correlated with the dry weight of the crown roots.

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