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Development and Distribution of the Corn Root System Under Field Conditions[1]

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ABSTRACT

The rate of corn (*Zea mays* L.) root growth in the field and root distribution in the soil as related to stage of plant growth has not been studied in detail. To obtain more information we measured the length, fresh weight, and distribution of corn roots at time intervals between planting and harvest in 1970 and 1971. The study was made on corn growing on Chalmers silt loam soil at Lafayette, Indiana. Grain yields were 6,160 kg/ha in 1970 and 11,700 kg/ha in 1971.

Root length and fresh weight increased rapidly for 80 days followng planting, remained relatively constant for 14 days, and then decreased rapidly when the plants were in the reproductive stage. A maximum root density of 4.1 cm/cm^3 occurred in the 0 to 15 cm zone at 79 days. The lower soil zones reached maximum root density 1 to 2 weeks later than in the 0 to 15 cm zone. Root density in the 0 to 15 cm zone was greater in cores taken midway between plants in the row than at other locations. Maximum root length was 153 cm/cm^2 of surface area at 86 days.

Additional index words: Root length, Root fresh weight, Root density, Shoot weight.

ALTHOUGH development of corn (*Zea mays* L.) shoots during their growth cycle has been well documented (Sayre, 1948; Hanway, 1963), few investigations have been made on the root system. The size, distribution, and rate of development of corn roots are important because of their influence on the supply of soil nutrients and soil water available to the plant. Since little information exists, a study of the development of the corn root system under field conditions was initiated.

The objectives of this investigation were: 1) to measure the length, fresh weight, and distribution of corn roots at various intervals between planting and harvesting; and 2) to determine the relationship between root development and the growth stages of the corn shoot.

Methods that have been used to study corn roots in the field include excavating the entire root system of isolated plants (Haynes, 1889; Weiling, 1935), excavating a slab of soil containing a portion of the roots of corn plants grown at usual populations (Foth, 1962), examining the face of soil containers in a rhizotron (Taylor et al., 1970), and sampling with soil cores to estimate the amount and distribution of roots (Raper and Barber, 1971; Barber, 1971). Of these methods, subsampling the root system with core samples is the least laborious and also facilitates replication, and was therefore chosen for root sampling of plants older than four weeks.

MATERIALS AND METHODS

A study of root growth was made in 1970 and 1971 on corn growing on Chalmers silt loam, a Typic Argiaquoll, at the Purdue University Agronomy Farm, Lafayette, Indiana. The soil properties are shown by 15-cm depth increments in Table 1. Consolidated soil beginning at approximately 75 cm restricted root growth below this depth.

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Table 1. Soil properties by depth increment.

Depth	pH*	Organic matter	Bulk density	Soluble nitrate-N	Available P†	CEC	Exchangeable K	Exchangeable Ca	Exchangeable Mg
cm		%		ppm	ppm	meq/100g	meq/100g	meq/100g	meq/100g
0-15	5.4‡	4.7	1.35	59	16	30.6	0.5	14.3	5.7
15-30	5.6	4.8	1.48	12	7	30.6	0.4	15.6	6.8
30-45	5.9	2.7	1.40	6	1	29.0	0.2	15.8	6.8
45-60	6.2	1.4	1.50	6	2	27.0	0.2	15.8	7.4
60-75	6.3	0.5	1.56	5	5	24.4	0.2	14.8	6.9

*pH in 0.01M $CaCl_2$. †Bray P_1. ‡All values are means of five replicates.

1970 Study

A 30 × 30 m area of uniform soil was selected. Tillage consisted of fall plowing and disking twice in the spring. Broadcast before disking in the spring were 280 kg N, 47 kg P, and 91 kg K per ha. Corn was planted May 27 in rows 71 cm apart at a rate of 59,300 kernels/ha. Weed growth was controlled chemically without cultivation.

The area was divided into three 10 × 30 m areas to give three replicates. One plant was sampled at random from each area on nine dates during the growing season. Both roots and shoots were sampled. Grain yield was determined at maturity. Two systems of root sampling were used. On June 11, 13, 15, 17, and 19, when plants were small, one plant was excavated from each plot in a cylinder of soil 30 cm in diameter by 30 cm deep. Care was taken to ensure that all the roots were obtained. Later, on July 15, August 4, August 17, and September 1, three soil cores were taken around one randomly selected plant in each plot. The cores were taken with a Giddings hydraulic soil probe mounted on a truck. Cores were 7.62 cm in diameter and 75 cm deep. All cores were taken on a line extending perpendicular to the row. The first core was immediately adjacent to the plant; the second, 18 cm from the plant; and the third, midway between the rows. The cores were divided into 15-cm depth sections. The plant adjacent to the cores was harvested and measured for dry shoot weight.

1971 Study

The sample plots were arranged in a completely randomized design with 5 replications of 14 sampling dates plus 11 additional plots for measuring grain yield. The 1971 site, adjacent to the 1970 site, was 15 × 92.4 m and consisted of 3 tiers of 22 six-row plots of 5 × 4.2 m. Plots sampled by excavation on the first three dates were used later for sampling with the hydraulic probe. Tillage, fertilization, and weed control were the same as in 1970. Corn was planted May 5 in rows 76 cm apart at a population of 111,000 kernels/ha. The corn was thinned to 53,600 plants/ha when it was 25 cm tall. A six-row border surrounded the plot area.

Corn shoots and roots were sampled by excavating the whole root system on May 26, 28, and 30. On June 8 and on 10 subsequent dates through September 14, a randomly selected plant was sampled using soil cores on each of 5 randomly selected plots. The core location in 1971 was different from that in 1970. The first core was taken directly over the stump of the harvested plant; the second, midway between the rows and opposite sample 1; the third, midway between the first core and the adjacent plant in the row; and the fourth, 25 cm from the row on a line between samples 2 and 3. The soil cores and plants were handled as in 1970. Separate soil cores were taken at each sampling site on each date to obtain soil for measurement of soil moisture content by depth. Soil samples for analysis were also taken by depth increments at each sampling.

Laboratory Analyses

Root Separation. With whole root excavation, the roots and soil were soaked in 0.1% $(NaPO_3)_6$ for 4 hours; then the roots were separated by washing the soil through a 40-mesh sieve. With core samples, the soil was washed from the roots by placing the core in 0.1% $(NaPO_3)_6$ on a screen mounted in a plastic bucket and shaking slowly on a mechanical shaker. Root length was measured using Newman's line-intercept method (1966). Root weight was determined after removing excess water with absorbent paper.

Soil moisture was determined as weight percent by weighing soil samples before and after drying at 105C. Corn shoots harvested at each sampling date were dried in a forced-air oven at 60C for a minimum of 72 hours, weighed, and ground, and a subsample was retained for chemical analysis.

Calculations

Root length and weight were determined in the 0 to 15 cm layer by assuming the root system grew in a uniform concentric pattern. The contribution of each core sample was weighted to give the proportionate volume it represented. Below 15 cm, the cores were considered as replicates since there was no apparent difference due to core position in the amounts of roots. Mean coefficients of variation were used to indicate the experimental error of measurements on individual plants since the coefficient of variation (C.V.) was relatively constant with plant age.

RESULTS AND DISCUSSION

Shoots and roots of corn grown with one uniform fertility treatment were sampled throughout the growth cycle in 2 years. Corn was planted late in 1970 and grain yield was only 6,160 kg/ha. In 1971 corn was planted earlier resulting in a larger grain yield of 11,700 kg/ha. The difference between years provided a contrast for evaluation of root and shoot growth. Mean shoot dry weight, total root length, and total root fresh weight per plant for each sampling date in 1970 and 1971 are given in Table 2. The more rapid early growth of shoots and roots observed in 1970 reflects the higher temperature resulting from later planting. The corn reached 75% silking at 68 days in 1970 and 75 days in 1971. During both 1970 and 1971 root length and shoot dry weight increased rapidly in the first 80 days. This period corresponds to vegetative growth of the plant. From 80 to 94 days root length remained relatively constant. During this period, corresponding to the transition from vegetative to reproductive growth by the plant, shoot dry weight increased rapidly. In 1971 measurements at 100 days and thereafter showed a marked decrease in root length per plant even though shoot dry weight was increasing. In 1970, no measurements were made beyond 96 days and no reduction in root length with plant age was observed. The decline in root length measured in 1971 occurred during the reproductive portion of the corn growth cycle.

Observations of the roots indicate that after tasseling, roots were dying and new roots were being formed. Because of this the roots measured at any time represented the difference between the roots

Table 2. The effect of plant age on mean* shoot dry weight, root length, and fresh weight per plant of corn grown on Chalmers silt loam in 1970 and 1971.

Plant age	1970 Shoot dry weight	1970 Root length	1970 Root fresh weight	1971 Shoot dry weight	1971 Root length	1971 Root fresh weight
days	g	m	g	g	m	g
15	0.4	4	0.6			
17	0.7	6	0.9			
19	1.0	10	1.5			
21	1.4	9	1.6	0.6	4	1.2
23	3.7	11	3.2	1.1	9	2.5
25				1.3	14	3.7
34				8.4	298	35.7
42				30.9	650	83.4
49	67.5	1490	68.3	69.4	1155	123.7
56				107.5	1628	139.2
69	129.4	1535	86.7			
71				199.3	2152	248.8
79				233.8	2807	291.2
82	194.4	2154	106.3			
86				243.6	2864	139.1
93				296.9	2841	224.7
96	298.6	2250	139.9			
100				367.9	1605	110.2
113				414.3	1524	130.2
132				435.1	966	112.6
Mean C.V.	18.9	22.3	24.6	12.6	16.2	27.7

*Values for the last four dates in 1970 are means of three samples, all others are means of five samples.

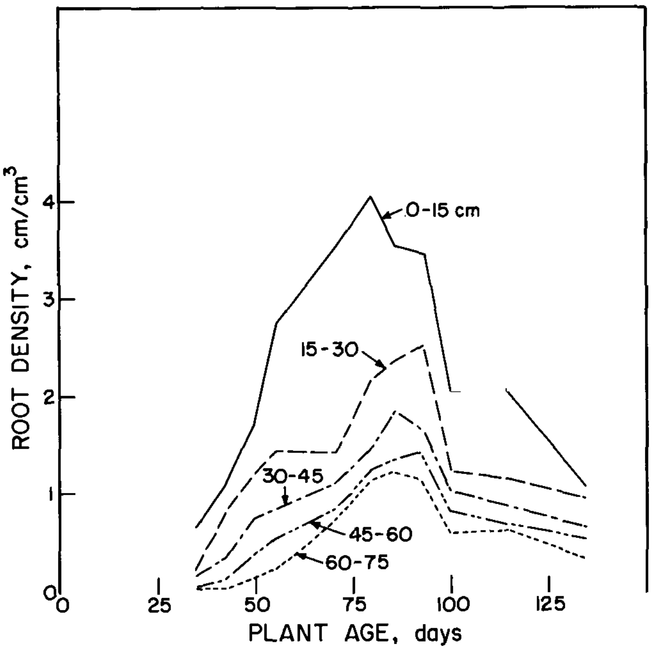

Fig. 1. Relation of plant age to root density at five soil depths during corn growth in 1971.

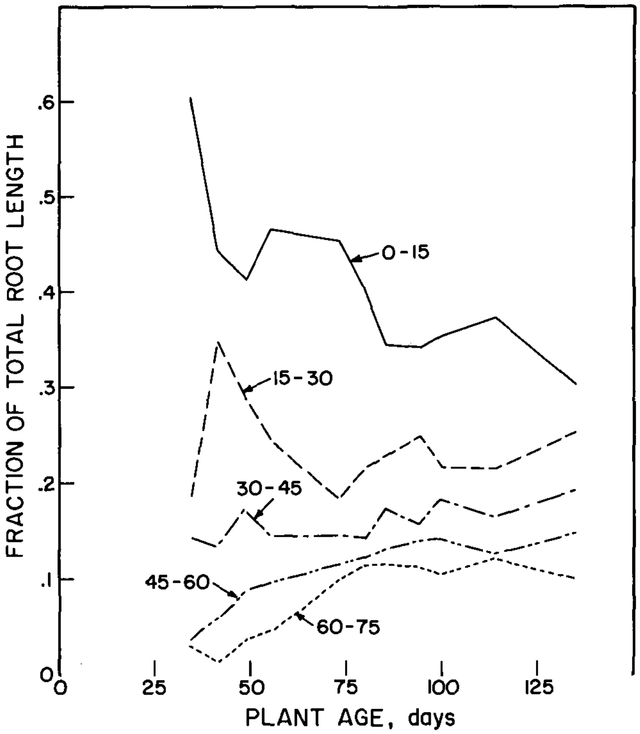

Fig. 2. Relation of plant age to the decimal fraction of the roots present in each of five soil depths during corn growth in 1971.

produced and those that had died. During the early growth of the plant it is probable that only a few roots were dying. However, because roots were dying at later growth stages it was not possible to estimate the total amount of roots that were produced. To our knowledge this is the first observation of corn roots dying and root length decreasing while shoot weight was increasing. Taylor et al. (1970) did not find a reduction in root length on measurements made up to 107 days in a rhizotron. Their corn plants were grown without plant-to-plant competition and this may have influenced the results.

The growth stage when the amount of living roots present reaches a peak and then starts decreasing influences the time for sampling roots when only one sampling is made to measure the extent of the root system. In our experiment, sampling at tasseling appeared to be the best time to obtain root samples.

Both fresh root weight and root length were measured and they gave similar results. The average C.V. was greater for root weight measurements than for root length.

Root Distribution

The relative distribution of the roots in the soil changed as plant growth progressed. Mean root density, expressed as cm of root per cm^3 of soil volume, at five depths within the soil is shown in Fig. 1 for samples collected in 1971. The highest density occurred in the 0 to 15 cm zone, where a maximum density of 4.05 cm/cm^3 was found at 79 days. The maximum density in zones below the 0 to 15 cm zone occurred 1 and 2 weeks later. After reaching a maximum, root length decreased in all depth zones as the plant matured.

The relative proportion of roots found in each zone (Fig. 2) changed with plant age. At 34 days, 0.66 of the roots were in the 0 to 15 cm zone. This decreased progressively with age reaching 0.30 at 132 days. The soil in these experiments was believed physically suitable for root growth in the top 75 cm. It consisted of a 75-cm depth of loess over glacial till. There was little root growth into the more consolidated glacial till. Soil moisture and soil aeration were suitable for root growth in the 0 to 75 cm layer throughout the growth period for both years. The soil was tile-drained with tiles at 20-m spacing. The soil fertility (Table 1) was high in the 0 to 15 cm layer but much lower in the subsurface layers. While this may have reduced root growth in the subsoil as compared to the 0 to 15 cm layer, this fertility distribution is a characteristic common to many Corn Belt soils. The restrictive layer at 75 cm probably did not have much influence on the rate of root growth vertically since most roots are usually found in the upper 75 cm of soil.

Root distribution lateral to the axis of the corn plant was determined by measurements made on cores taken at different positions. There was a difference due to core location in the 0 to 15 cm layer but not at depths below 15 cm. The effect of core location on root density for the 0 to 15 cm layer is shown in Fig. 3 for samples taken in 1971 and in Table 3 for samples taken in 1970. Since no variation in lateral distribution of roots occurred at depths below 15 cm, these data are reported as the mean for each depth (Fig. 1). Root density for cores taken directly beneath the corn plant was much greater than that for other locations early in the growth period. At silking, root density was greatest for samples taken midway between plants in the row. The spacing between plants in the row averaged 24 cm. The cores taken in the inter-

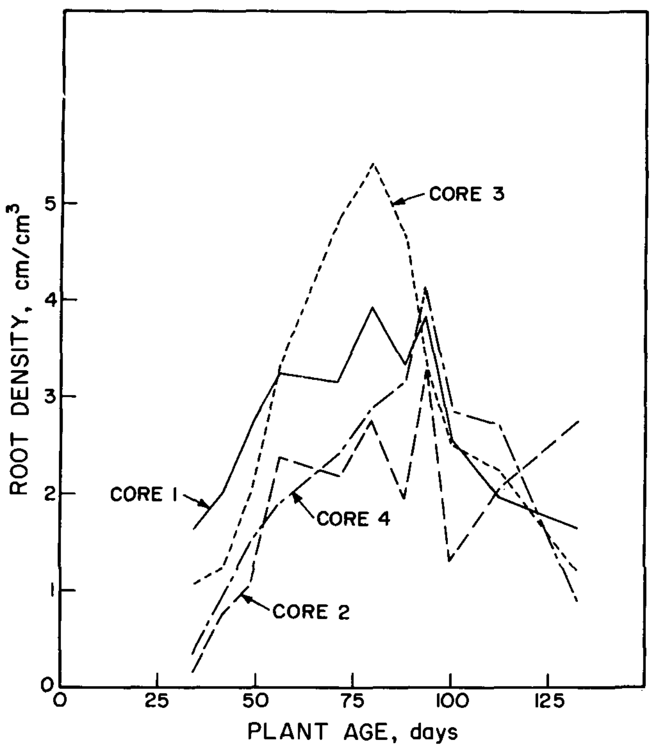

Fig. 3. Relation between core location and root density in the 0 to 15 cm depth zone for corn grown in 1971. Core 1, directly under the plant; core 2, midway between the rows; core 3, midway between plants in the row; core 4, midway between cores 2 and 3.

row space (cores 2 and 4 in Fig. 3) showed a lower root density than those taken in the row for the first 85 days of growth. Root densities were also greater for samples taken adjacent to the plant in 1970 (Table 3); these densities were double those taken in the interrow space. The soil was not cultivated following planting in either 1970 or 1971 because cultivation may alter root distribution in the 0 to 15 cm layer, particularily if done after many roots have developed in the cultivated zone.

Soil Moisture

Since soil moisture conditions may affect root growth, soil moisture was measured each time roots were sampled in 1971 by taking separate cores alongside the cores for root measurement. Rainfall occurred frequently throughout the growing season so the moisture content of all soil zones only varied between 24 and 29%. The moisture content of this soil was approximately 29% at field capacity and 13% at the wilting point. The soil area was tile-drained with tiles at 1 m depth and 20-m spacing. There appeared to be little limitation of root growth by soil moisture or aeration stress. There was not a significant correlation between soil moisture and root density. Although a lower soil moisture content at high root densities might have been expected, frequent rainfall limited the degree of moisture depletion that occurred.

Table 3. Plant root density in the 0 to 15 cm depth as influenced by plant age and distance from the corn row, 1970 data.

Plant age	Sample distance from the row		
	2 cm	18 cm	35 cm
days		cm/cm³	
49	1.6	1.2	0.8
69	1.8	1.1	0.7
82	2.2	1.6	1.0
96	2.7	1.8	1.4

CONCLUSIONS

During the later stages of growth of the corn plant, new roots were produced and older roots died and root measurements showed the net amount of roots present rather than the total produced. During vegetative growth of the plant, roots grew rapidly and few if any roots died; thus, the amount of roots present increased exponentially. As the plant changed from vegetative to reproductive growth, roots were dying as fast as new roots were produced but net root length remained constant. Later, during reproductive growth, the production of new roots was less than senscence of old roots so that the net root length present decreased rapidly.

Distribution of corn roots in the soil will influence the uptake of both water and nutrients. Knowledge of the change in distribution as the plant develops can explain the effects of drouth stress on corn growth. Knowledge of the variation of root density, both vertical and horizontal, in the soil can lead to development of the most effective placement of fertilizer in the soil. The research described herein showed the change in root growth and distribution as the corn plant developed. While distribution may vary due to soil, climate, and cultivar, the data obtained are useful as a benchmark value for evaluating the significance of corn roots in their contribution to the growth of the plant since data of this type have not been obtained previously.

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