pel. 1977. Dry weight reduction in mechanically-dwarfed tomato plants. J. Amer. Soc. Hort. Sci. 102(5):605–608.
10. Mitchell, C.A., C.J. Severson, J.A. Wott, and P.A. Hammer. 1975. Seismomorphogenic regulation of plant growth. J. Amer. Soc. Hort. Sci. 100(2):161–165.
11. Neel, P.L. and R.W. Harris. 1971. Motion-induced inhibition of elongation and induction of dormancy in *Liquidambar*. Science 1973:58–59.
12. Pappas, T. and C.A. Mitchell. 1985. Effects of seismic stress on the vegetative growth of *Glycine max* (L.). Merr. cv. Wells II. Plant, Cell Environ. (In press)
13. Rees, D.J. and J. Grace. 1980. The effects of shaking on extension growth of *Pinus contorta* Douglas. Forestry 53:155–167.
14. Suge, H. 1978. Growth and gibberellin production in *Phaseolus vulgaris* as affected by mechanical stress. Plant Cell Physiol. 21:303–310.
15. Turgeon, R. and J.A. Webb. 1971. Growth inhibition by mechanical stress. Science 174:961–962.
16. Walker, W.S. 1957. The effects of mechanical stimulation and etiolation on the collenchyma of *Datura stramonium*. Amer. J. Bot. 47:717–724.
17. Walker, W.S. 1960. The effect of mechanical stimulation on the collenchyma of *Apium graveolens* L. Iowa Acad. Sci. 64:177–186.

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Water Uptake and Root Distribution by Corn and Tomato at Different Depths

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Additional index words. *Lycopersicon esculentum, Zea mays*, root length and intensity, transpiration

Abstract. **Root systems were studied to determine if differences in utilization of soil moisture were associated with the extent and number of roots produced by corn and tomato. Growth room studies for both crops indicated that the reduction in transpiration when the upper portion of the root zone was dry was greater than when the lower portion was dry. Total root length of corn was about twice that of tomato roots. However, no direct relationship between the total amount of root length and transpiration was found. Roots of corn and tomato in the field extended beyond the maximum depth measured (100 cm) between 42 – 46 days after establishment. The spatial density of corn roots was much greater than that of tomato roots, especially as depths increased. This difference possibly explains the use of stored soil moisture by corn. On the other hand, the capacity of tomatoes to extract large amounts of water from the soil cannot be explained by the density and rooting depth. Perhaps this capacity is due to total root surface area differences or high absorption capacity of tomato root system.**

Different capacities to utilize soil moisture are related to differences in rooting habit among plant species (2, 4, 9). Traditionally, such differences in root habit have been referred to rather casually as differences in depth of rooting. Lorenz and Maynard (5) classified several vegetable crops according to their depth of rooting and used such classification as the basis for recommending irrigation practices. Fulton (4) demonstrated that although the maximum rooting depth of potatoes, corn, and tomatoes were similar, these vegetables differed in extraction of stored soil moisture.

The experiments reported in this paper were performed to learn more about root-distribution patterns of corn and tomatoes. The effect of water application at different root-zone positions on total water use of crops also is reported.

Transpiration rates, when applying water to different proportions of the root system, were measured in the growth room. Cylinders 15 cm in diameter and 80 cm in depth were fabricated from sheet metal, fitted with observation windows covering almost the total length, lined with plastic film, and filled with a potting soil mixture containing 2 muck : 1 peat : 1 sandy loam (by volume). In a first phase of these experiments, thin layers of soft wax were placed at 20, 40, and 60 cm from the surface. Rubber tubes were installed just below the wax layer so that water could be added from the soil surface or through the tubes to keep all soil (100%) or the lower 75%, 50%, and 25% of the cylinder wet.The lower end of the cylinder was fitted with a fine screen to allow drainage of excess water. In a second phase, thin layers of soft wax also were placed at 20, 40, and 60 cm from the surface so that water could be added from the soil surface to keep the upper 25%, 50%, 75%, or 100% of the soil of the cylinder wet.

Corn and tomatoes were grown to 4-week seedlings. For each treatment, one plant of similar size in each species was transplanted to a separate cylinder of soil located in a growth room held at 23°C during the day and 18° at night. The day length was 14 hr. Water

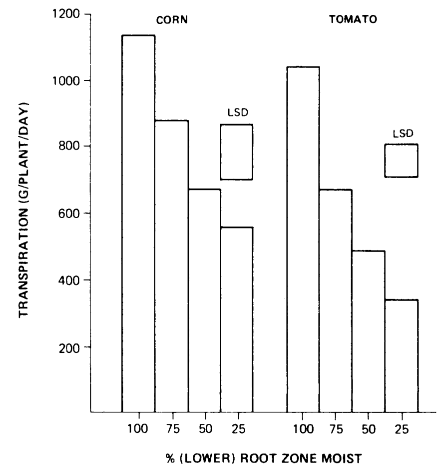

Fig. 1. Effect of maintaining the total root zone (100%) or the lower 75%, 50%, and 25% of the root zones moist on transpiration of corn and tomato. Also shown are LSD values between treatments at the 5% level of significance.

was added to each column daily to wet the whole soil volume until observation indicated that roots had penetrated the whole soil mass (30 days after transplanting in cylinders). Subsequently, water was added to 25%, 50%, 75%, or 100% of the root zone by applying water through the appropriate tubes (for wetting lower portions) or to the surface where the upper portions were kept wet. All treatments were replicated 3 times. Cylinders were covered with aluminum foil to prevent evaporation and were weighed to measure transpiration on 8 consecutive days. Sufficient water was added daily to keep the wetted portion moist. The observation window provided a means of preventing the build-up of excess water above the wax layer in that zone. At the conclusion of the experiment, the oven dry weight and length of the roots in each quarter of the root zone of one replicate were measured.

The first day following water application treatment, transpiration was identical with the water applied to the upper or lower 25%, 50%, 75%, or 100% of the root zone. The whole root zone was still wet, and moisture stress had not developed sufficiently in one day to reduce transpiration. Subsequently, the daily rate of transpiration diminished as the proportion of the root zone kept wet was reduced. On the 8th day following initiation of the water treatments, transpiration from corn and tomatoes with the lower 75% of the root zone wet was less than that with the whole root zone wet (Fig. 1). Similarly,

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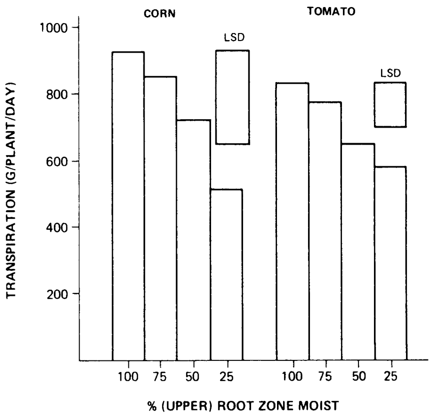

Fig. 2. Effect of maintaining the total root zone (100%) or the upper 75%, 50% and 25% of the root zones moist on transpiration of corn and tomato. Also shown are LSD values between treatments at the 5% level of significance.

transpiration of tomatoes was reduced significantly as the moist zone was reduced to the lower 25% of the vertical depth, whereas a significant reduction in transpiration rate of corn was measured to the lower 50% of the vertical depth.

When the upper part of the corn and tomato root zones were kept moist and the lower part allowed to become dry, transpiration decreased as observed for the reversed situation, but the effect was not as great (Fig. 2).

Observations from a single large data set (unreplicated) showed the total weight of corn roots grown in cylinders in the growth room with water applied to the lower 25%, 50%, 75%, and 100% of the root zone to be about 3 to 4 times greater than that of tomato roots. Similarly, total root length of corn was about twice that of tomato roots. Regardless of the proportion of soil kept moist, the weight and length of roots were much greater in the top 25% of the root zone than in any other portion, especially for tomato roots.

In the field experiment, tomatoes and corn were planted along the sides of two root observation pits. Root growth of both crops was observed through glass panels built in to the soil profile as described by Rogers (8). The soil, belonging to the Hapludalf subgroup, was a well-drained loamy sand soil consisting of 76 sand : 19 silt : 5 clay (by weight). The visible roots represent a vertical cross section of the root system of spaced plants grown under commercial conditions. Two observation pits were constructed with 4 glass panels on each of 2 sides. The glass was reinforced with wire at 1.27-cm intervals in both directions, thus dividing the panels in cells 1.27-cm square. Each panel exposed a profile 40 cells wide (horizontal) by 80 cells deep. The presence or absence of roots in each cell was recorded in June, July, and August during the growing season.

Root distributions of corn and tomato grown in the field at various times and different soil depths are given in Table 1. The horizontal intensity of the root system within each 10-cm layer is indicated by the percentage of horizontal squares of viewing surface occupied by roots (referred to as "root intensity") (11). Roots of both crops were confined almost entirely to the top 50 cm of the soil profile about 28 days after transplanting tomato seedlings and 42 days after sowing corn. For this time period, the horizontal intensity of rooting was considerably greater for tomatoes than for corn. Root growth of both crops was very extensive 42 and 56 days after transplanting tomato and corn, respectively, but the intensity of corn roots exceeded that of tomato roots at all depths except the surface 10 cm. Roots of both crops continued to grow during the remaining of the growing season, but the intensity decreased between 56 – 70 days for tomato, and 70 – 84 days after sowing corn. The final rooting intensity of corn was much greater than that of tomatoes at all depths below 10 cm.

The decrease in transpiration when the upper portion of the root zone was dry was much greater than when the lower portion was dry. This decrease may relate to the greater weight and length of roots in the top 25% of the root zone compared to deeper depth. The decrease in transpiration, however, was not proportional to the decrease in amount of roots present. Others have reported nonlinear relationships between the amount of root on the plant and transpiration (1, 7). Transpiration rate was controlled in the vapor phase, which was indirectly affected by the root through changes of leaf-water status and hence stomatal aperture. Therefore, a simple relationship between root density and transpiration rate would not be expected.

In the growth room, corn root length was much greater than tomato root length, especially below 20 cm. Taylor et al. (11) also reported total corn root length to be about 3 times that of tomato. However, tomato plants transpired substantially more water than corn when rates were expressed as g/m root length/day or g/g root dry weight/day. In the field, the rooting intensity of tomatoes was very high in the surface 20 cm of soil but declined sharply between 20 and 50 cm. From 50 to 100 cm, the rooting intensity remained fairly constant (Table 1). Corn, on the other hand, had dense root systems at all depths 70 days after planting (Table 1). The root intensity decreased at the end of the growing season for both corn and tomatoes (Table 1). Van der Past (12) reported that tomato roots grew fast during the first few months and the number of roots decreased sharply at the beginning of the harvest of fruit. Similar results were reported for corn by Mengel and Barber (6). They indicated that new roots were produced and old roots died during the later stages of corn growth. As the plants changed from vegetative to reproductive growth, roots died as fast as new roots were produced, but net root length remained relatively constant.

Corn has a very high evapotranspiration rate but nevertheless extracts large quantities of stored soil moisture (3, 4). This capacity to extract water probably relates to its extensive root system at greater depths. The tomato root system was spatially dense near the surface and, in contrast to corn became quite sparse below 20 cm. The extraction of large amounts of water from the soil by tomato cannot be explained by the density or amount of root system, but possibly it is due to high amount of total surface area or high absorption capacity of tomato root system, as suggested by Tan et al. (10).

Table 1. The percentage of horizontal squares occupied by roots for corn and tomatoes at various times and soil depth during the growing season.[z]

Soil depth	Corn, days after transplanting				Tomatoes, days after transplanting			
(cm)	42	56	70	84	28	42	56	70
0–10	29	43	61	54	44	60	62	66
10–20	31	61	75	65	42	45	65	57
20–30	17	59	68	62	29	45	49	43
30–40	10	63	71	68	18	47	36	30
40–50	3	62	74	67	9	42	31	22
50–60	0	32	55	51	1	21	23	12
60–70	0	27	57	56	1	22	27	18
70–80	0	24	64	62	0	21	33	21
80–90	0	18	63	60	0	20	37	23
90–100	0	15	60	59	0	16	38	24

[z]Single observation.

Literature Cited

1. Christersson, L. and S. Pettersson. 1968. Water and sulphate uptake at root reduction in Ricinus communis. Physiol. Plant. 21:414–422.
2. Durrant, M.J., B.J.G. Love, and A.P. Draycott. 1973. Growth of crop roots in relation to soil moisture extraction. Ann. Appl. Biol. 74:387–394.
3. Fulton, J.M. 1970. Relationships among soil moisture stress, plant populations, row spacing and yield of corn. Can. J. Plant Sci. 50:31–38.
4. Fulton, J.M. 1970. Relationship of root extension to the soil moisture level required for maximum yield of potatoes, tomatoes and corn. Can. J. Soil Sci. 50:92–94.
5. Lorenz, O.A. and D.N. Maynard. 1980. Knott's Handbook for vegetable growers. 2nd ed. Wiley, New York.
6. Mengel, D.B. and S.A. Barber. 1974. Development and distribution of the corn root system under field conditions. Agron. J. 66:341–344.
7. Parker, J. 1949. Effects of variations in root-leaf ratio on transpiration rate. Plant Physiol. 24:739–743.
8. Rogers, W.S. 1968. The East malling root-observation laboratories, p. 361–376. In: W.J. Whittington (ed.). Root growth, proceedings of the fifteenth Easter School in Agricultural Science, Univ. of Nottingham. Willaim Clowers & Sons, London.
9. Stone, L.R., I.D. Teare, C.D. Nickell, and

W.C. Mayaki. 1976. Soybean root development and soil water depletion. Agron. J. 68:677–680.
10. Tan, C.S., A. Cornelisse, and B.R. Buttery. 1981. Transpiration, stomatal conductance, and photosynthesis of tomato plants with various proportions of root system supplied with water. J. Amer. Soc. Hort. Sci. 106(2):147–151.
11. Taylor, H.M., M.G. Huck, B. Klepper, and Z.F. Lund. 1970. Measurement of soil-grown roots in a rhizotron. Agron. J. 62:807–809.
12. Van der Post, C.J. 1968. Simultaneous observations on root and top growth. Acta Hort. 7:138–144.

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Water Management of Greenhouse Tomatoes

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Additional index words. *Lycopersicon esculentum*, tensiometers, drip-irrigation, soilless medium

Abstract. **Crack-susceptible and crack-resistant tomato (*Lycopersicon esculentum* L. Mill.) cultivars were grown in soil beds and in bags filled with a peat-vermiculite mix. Plants in soil were drip-irrigated 1 or 4 times daily, or hand-watered every day or as needed based on soil moisture tension. Plants in bags received only drip-irrigation treatments. Genotype had the greatest effect on fruit cracking, with 3.8% by weight cracked fruit in the crack-resistant compared to 35.3% in the crack-susceptible cultivar. Growing plants in bags reduced the weight and the percentage of cracked fruit per plant, but, in both cultivars, total and No. 1 fruit weights were greatest from the soil treatments with drip-irrigation. Irrigation frequency and method did not affect fruit weight except in the crack-resistant cultivar grown in bags where increasing irrigation frequency increased weights. Cracking was decreased by 22% in tomatoes irrigated manually every day, compared to those irrigated only when needed. In the soil treatment, raising the irrigation frequency significantly decreased cracking in the susceptible, but not in the resistant cultivar. In the soilless treatment, frequent irrigation increased cracking in both cultivars.**

Cracking of tomato fruit is of major concern to growers and has resulted in substantial crop loss in the United States and England (2, 7, 12, 13, 14). Cracking of greenhouse and field grown fruit has been attributed to rapid fluctuation in soil moisture during fruit maturation and to water on the surface of the fruit (3, 8, 9, 10). Cracking is of major concern among greenhouse tomato growers in North Carolina, where plants grown in bag culture frequently are watered daily as much as 10–20 times, as opposed to the daily recommended rate of 1–2 times (2, 12). Little is known of the effects of this increase in irrigation frequency on fruit cracking. Therefore, the purpose of this study was to investigate the effects of different media and increased irrigation frequency on radial fruit cracking and yield in greenhouse-grown tomatoes.

Seed of 'Michigan-Ohio Hybrid' (MO) and 'Montfavet 63-5-F1 Hybrid' (MF), were sown on 4 Dec. 1981, and transplanted on 16 Dec. into 7.6 cm peat pots containing a mixture of 50 sphagnum peat moss: 50 finely ground vermiculite (Jiffy Mix, W.R. Grace Co., Cambridge, Mass.) (v/v). Seedlings again were transplanted on 2 Feb. 1982, into either a fine sandy loam soil in beds 2.4 m long × 1.2 m wide × 0.3 m deep, or into 11.4 cm white, open-bottomed pots containing peat-vermiculite mix. These pots then were sunk to a depth of 4 cm in 0.057 m^3 Terralite 'Plant 'N Bags' (W.R. Grace Co., Cambridge, Mass.) allowing 0.30 m^2 area per plant. The bags were slit on the side to allow for drainage and placed on the ground in raised beds over white plastic.

The 8 bag-cultured beds were drip-irrigated, half receiving water beginning at 1200 EST and half beginning at 0600, 1000, 1400, and 1800 EST daily. In the 16 soil beds, half received the same treatments as the bag-cultured beds, and half were hand-watered.

Soil moisture tensions in all treatments were recorded daily using mini-tensiometers (0.95 cm diameter × 2.856 cm length cup). Two tensiometers were placed in a representative bed for each treatment at a distance of about 5 cm on center from the plant and at a depth of about 8 cm on center in the medium.

From 2 Feb. to 2 Apr., 0.89 liter/plant/day of water was provided when soil moisture tensions reached 25.3 kPa in the soil beds. Preliminary investigations indicated this to be the maximum level of tolerance before wilting occurred. The level of irrigation was raised to 1.2 liters/plant/day on 3 Apr. and was raised again on 6 May to 1.77 liters/plant/day to maintain soil moisture tensions below 25.3 kPa. The bag treatments also were irrigated at this time so that the total amount of water and nutrients received would be similar to the drip-irrigated soil treatments. Half of the hand-watered treatments were watered only when the tensiometers indicated 25.3 kPa, whereas the other half were watered daily regardless of soil tension, receiving the same amounts of water as the tensiometer-controlled, drip-irrigated treatments.

Up to the time of first fruit set and after fruit set (in parentheses) drip-irrigated plants received 90 (126) ppm N, 50 (50) ppm P, 195 (202) ppm K, 155 (185) ppm Ca, and 44 (44) ppm Mg, plus micro-nutrients from stock solutions of calcium nitrate, calcium chloride, potassium nitrate, magnesium sulfate, and Chem-gro (Hydro-Gardens, Colorado Springs, Col.) injected into the irrigation lines. Solution pH and conductivity levels were monitored and maintained at pH 6.0 (6.0) and at 1000 (1200) microsiemens, respectively (5). Handwatered beds were fertilized following the Ontario fertilization schedule (14).

Plants were trained to a single stem, and flowers were shaken daily with an electric vibrating pollinator to increase the probability of fruit set. Fruit were harvested from 2 Apr. through 24 May, and the following data were recorded for all fruit at various stages of ripeness, beginning at the 'breaker' stage: total number, total weight, number of fruit cracked, total number of growth cracks, total length and depth of cracks, total weight of the cracked fruit, and total number and weight of defective fruit (excluding cracking). Since the number of cracks/fruit, total length and depth of cracks, weight of cracked fruit, and number of cracked fruit were all highly correlated (1), only weights are presented.

The experimental design was a random-

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