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Apple Root Distribution as Effected by Irrigation at Different Soil Water Levels on Two Soil Types

D.J. Beukes[1]

Department of Agriculture, Highveld Region, Private Bag, X804, Potchefstroom 2520, Republic of South Africa

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Abstract. **Apple trees (*Malus domestica* Borkh.) were grown in a field trial at soil water depletion (SWD) levels of 15% (wet) and 75% (dry). Water extraction depths were divided into 3 or 4 depth increments, and ranged from 700 to 1100 mm, depending on the treatments and rooting depth. Treatments were applied from the end of shoot extension growth until harvest. In a loamy sand and a loam soil, root distribution was affected primarily by the soil water regime. The treatments affected distribution with depth rather than root diameter. Shallower (about 600 mm), but more concentrated, root systems developed under the wet than dry treatment. The effect of soil water regime on root distribution was more pronounced in a loamy sand than in a loam. Treatment effects were probably diminished in the latter by high soil bulk densities.**

Root growth is a function of soil texture, water content, bulk density, soil pH, and soil strength. Interrelation among these factors necessitates their simultaneous consideration in any root growth investigation (6). According to Levin et al. (2), the main factor determining the distribution of apple roots under orchard conditions is the relation between soil water content and aeration. Gorin (2) found that low soil water contents caused apple root sytems to have 6% of the number of roots found in the controls, which received adequate irrigation. Goode and Hyrycz (1) report that the availability of soil water had a greater influence on distribution than on the total amount of fine roots. The main difference in distribution under various soil water regimes seemed to be the greater exploitation of the 0–150 mm soil layer under a wet regime.

One of the major objectives of an 8-year irrigation experiment with 'Granny Smith' apple trees was to investigate the effects of irrigation at different soil water levels on root distribution. Results from studies on soils of 2 rather different textural classes are presented.

Material and Methods

An 8-year irrigation project with 'Granny Smith' apple trees on Malling Merton 793 rootstock, consisting of 4 establishing and 4 observational years, was conducted at the Welgevallen Experimental Farm of the Univ. of Stellenbosch. The following mean climatic pattern was observed for a growing season lasting from 15 Oct. to 2 June, i.e., 231 days: 1) rainfall, 353 mm (annual: 685 mm); 2) class A pan evaporation, 1241 mm (annual: 1084 mm); 3) mean maximum and minimum air temperatures, 24.4° and 11.7°C respectively; and 4) mean sunshine duration, 7.4 hr day^{-1} with a peak of 9.7 hr day^{-1} from December to February.

According to MacVicar et al. (4) the soils of the experimental area are classified under 2 dominant soil forms, Dundee (no series) and Westleigh (Devon series). The USDA correlations are Aquic Xerofluvent and Aquicfluventic Xerochrept, respectively.

Dundee soil form. Particle size analyses (Table 1) indicate a mean clay, silt, and fine sand content of 7.6%, 8.9%, and 36.6%, respectively, for the 0–1050 mm soil layer. The texture is loamy sand (4). Mean bulk density was 1.42 g cm^{-3} for the 0–1050 mm soil depth. Soil pH for the same layer was 4.5. Field water capacity (FWC) of 14.1% by weight was measured in the field. A permanent wilting point (PWP) of 4.9% by weight was determined with the pressure apparatus at 1520 kPa on undisturbed soil cores.

Devon series. Particle size analyses (Table 1) reveal a mean clay, silt, and fine sand content of 20.6%, 16.1%, and 39.5%, respectively, for the 0–900 mm soil layer, indicating a loam texture (4). Mean bulk density for the 0–900 mm soil layer was 1.61 g cm^{-3}. Mean soil pH was 4.7. Values for FWC and PWP were 20.2% and 10.4%, respectively. The normal orchard soil preparation prior to planting included the adjustment of soil pH and macro nutrient status to commercially accepted levels. The trees were established in prepared holes in Aug. 1971. Rows were grouped in pairs with a distance of 6.0 m between pairs. In a pair of rows the spacing was 1.8 × 3.5 m. Standard fertilizer programs were followed with recommendations based on annual leaf analyses. The treatments were enforced from the 1975–76 to the 1978–79 season, and were delivered by a microjet irrigation system when a specific depletion level of plant available soil water (SWD level) was reached. Two levels, viz 15% (wet) and 75% (dry), were used and were replicated 4 times in a randomized block design. During the treatment period, which lasted from the end of shoot extension growth (about the end of January) until harvest, 380 mm of water was required in 13 irrigations to maintain the 15% SWD level, compared to 130 mm in 1 irrigation for the 75% SWD level. Mean amounts per application were 30 mm for 15% and 100 mm for the 75% SWD level. The 15% plots received an irrigation every 7 days and the 75% plots every 58 days.

Water extraction depths (WED) were based on annual root studies. For example, WED of 700 and 1100 mm were chosen during the 1978–79 season for the 15% and 75% SWD levels, respectively. For the purposes of soil water budgeting and irrigation scheduling, these extraction depths were divided into 3 or 4 depth increments with a point of soil water content (SWC) measurement in each layer. The amounts of available water in

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[1]Soil scientist.

Table 1. Textural analyses of soil types.

	Dundee soil form distribution					Westleigh form (Devon series) distribution				
Depth (mm)	Clay (%)	Silt (%)	Fine sand (%)	Med sand (%)	Coarse sand (%)	Clay (%)	Silt (%)	Fine sand (%)	Med sand (%)	Coarse sand (%)
150	8.9	11.1	39.5	31.2	9.4	16.9	11.0	47.5	17.4	7.2
300	8.7	9.6	41.9	31.8	8.1	19.4	12.3	44.5	17.5	6.3
450	8.8	9.1	40.8	32.9	8.4	20.5	17.2	39.6	17.1	5.7
600	6.7	9.3	36.5	36.9	10.6	22.1	18.9	35.4	17.5	6.1
750	6.5	7.7	31.5	40.8	13.5	23.3	19.0	35.4	17.1	5.2
900	3.7	5.2	24.6	47.2	19.4	21.6	17.9	34.5	19.7	6.3
1050	9.8	10.3	41.7	30.9	7.3	---	---	---	---	---
Mean	7.6	8.9	36.6	36.0	11.0	20.6	16.1	39.5	17.7	6.1

all depth increments were added for the whole 0–700 mm or 0–1100 mm profile to obtain the total amount of soil water above (or below) the SWD level. When the latter amount was zero (or negative) an irrigation was applied to recharge soil water to FWC.

The irrigation system yielded a uniformly wetted area of 7.5 m × 8.3 m per plot which consisted of 2 rows of 5 trees each. Soil water content was measured daily, or every other day by mercury manometer tensiometers and a neutron moisture meter at a 1 m distance from one representative tree of each plot. The locations of soil water determination were just off-center of the wetted area. Actual evapotranspiration (ET_a) was based on the decrease in soil water between consecutive measurements. In this region, annual root activity is restricted to the growing season with negligible growth during winter. Ideally, the effects of irrigation on root distribution should be studied during the season on new growth. Due to the destructive nature of the technique used, it was decided to limit the investigations to the end of August, i.e., winter, of each experimental year. Rectangular profile pits, with the long axis parallel to the tree row, were dug in the wetted area at 1 m distance at the closest point from the trunk of a representative experimental tree. The profile wall closest to the tree was 1.4 m in length with the tree trunk in the center. The soil around the cut-off roots was removed carefully, and a grid with a mesh of 10 × 10 cm was laid over the wall containing the roots. All roots in each 100 cm^2 were counted, and their diameters were then measured and allocated to 5 diameter classes, viz < 1 mm, 1–3 mm, 3–5 mm, 5–10 mm, and >10 mm. The number of roots then was expressed as a percentage of the total number counted. The root maps were digitalized electronically and the data fed into a computer with a linked-up plotter which produced complete root profiles.

Four pits were dug per season with one per SWD level on each of the loamy sand and loam soils. Since there was no replication in pits, the different years were used as replications to perform analyses of variation. Arcsine transformation (3) was used on the data. Results of 1977, 1978, and 1979 will be included in the analyses. The investigations in Aug. 1979 included duplicate determination of soil bulk density in the profile wall, while samples for pH measurement also were taken.

Results

The means of the 3 years indicate that irrigation at different depletion levels had little effect on root diameter distribution for the Dundee form (Table 2). The difference in the 3–5 mm group, however, is significant at a 10% level. Fewer roots were found in the <1 mm group for the 15%, as compared to the 75% SWD level on the Devon series. In the 1–3 mm group, however, the situation was reversed. For both groups, differences were statistically significant. When the 2 soil types were compared, irrespective of the SWD levels, noticeable differences in root diameter distribution were found. On the Dundee form almost all roots (87%) were contained in the <1 mm group, while on the Devon series the majority of roots occurred in 2 diameter groups, i.e., <1 mm and 1–3 mm (Table 2). Horizontal root distribution along the soil profile was independent of the distance from the trunk (Fig. 1–4), which indicates that uniform root layers existed among trees within the orchard rows.

Dundee soil form (loamy sand). After 3 years the 0–600 mm soil layer contained 88.0% of the roots for the 15% SWD (wet) and 57.7% for the 75% SWD (dry) levels. The difference is statistically significant (Table 3). The dissimilarity in root distribution can be seen in Fig. 1 and 2. In Aug. 1977, after 2 experimental seasons, the majority of roots were concentrated

Table 2. The percentage of distribution of roots in diameter groups for soil types and SWD levels.

Soil type	SWD level (%)	Root diameter (% ± SE in group)[z]				
		<1 mm	1–3 mm	3–5 mm	5–10 mm	>10 mm
Dundee	15	87.0 ± 1.9	9.5 ± 1.1	1.6 ± 0.4	1.1 ± 0.6	0.6 ± 0.1
	75	87.0 ± 0.4	8.1 ± 0.7	2.6 ± 0.8	1.1 ± 0.4	1.3 ± 0.5
	F-value[y]	0.0	0.7	11.4	0.0	1.1
Devon	15	76.0 ± 5.8	18.8 ± 4.7	3.8 ± 1.6	0.9 ± 0.0	0.5 ± 0.0
	75	82.7 ± 3.8	12.6 ± 2.8	2.5 ± 0.6	1.1 ± 0.5	1.3 ± 0.6
	F-value	22.6*	61.9*	1.0	0.0	0.7

[z]Means of 1977, 1978, and 1979.
[y]F (P = 0.1) = 8.5.
*Significant at P = .05.

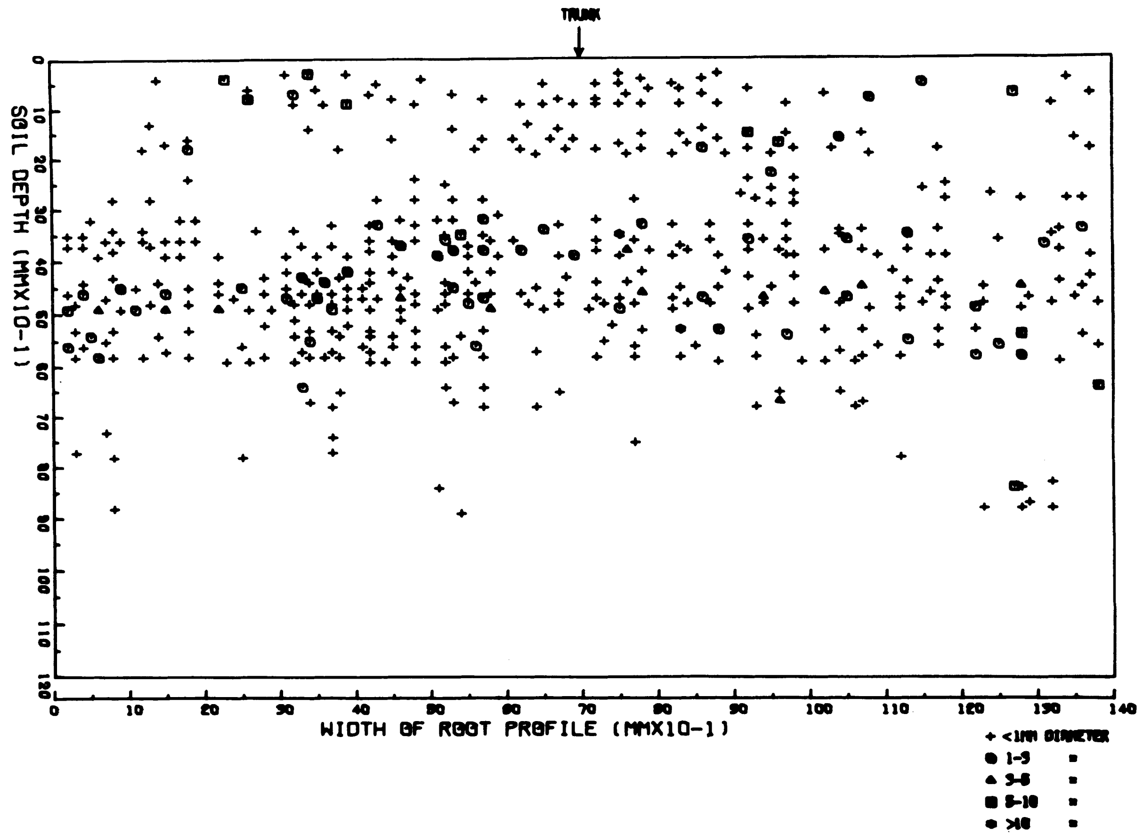

Fig. 1. Root distribution on Dundee form in Aug. 1977 for the 15% SWD level.

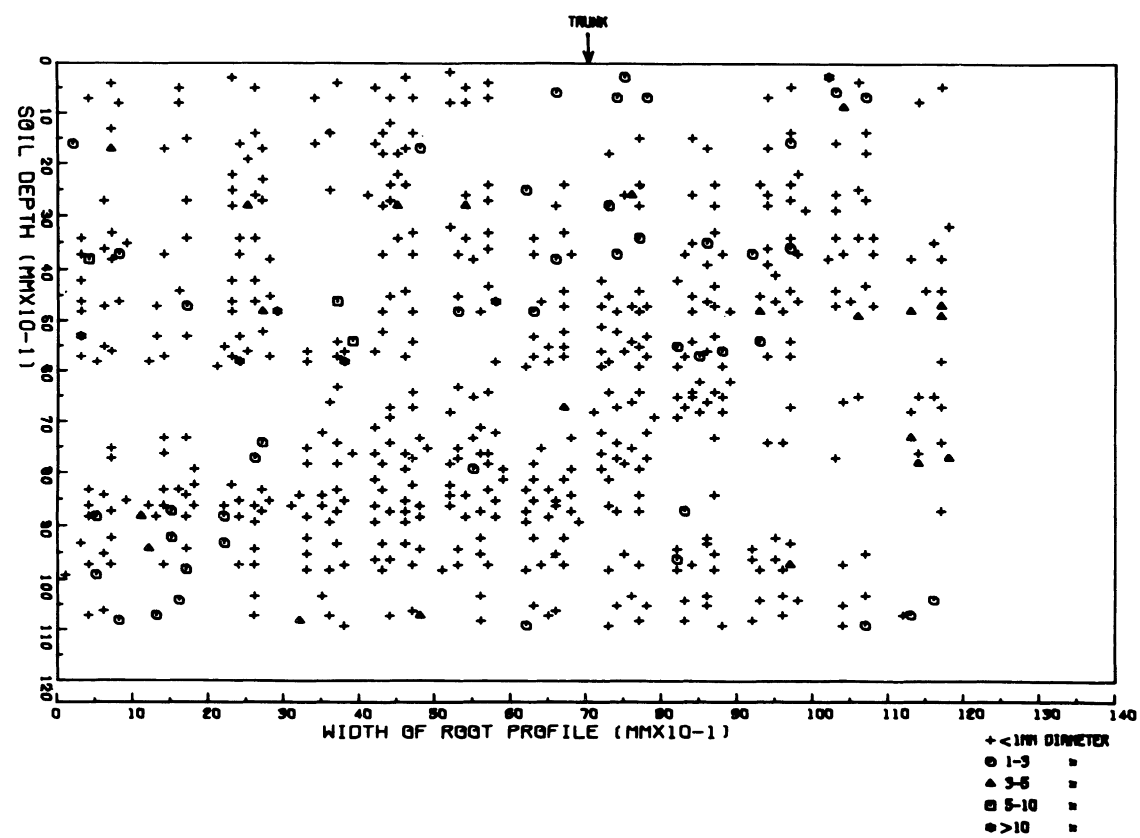

Fig. 2. Root distribution on Dundee form in Aug. 1977 for the 75% SWD level.

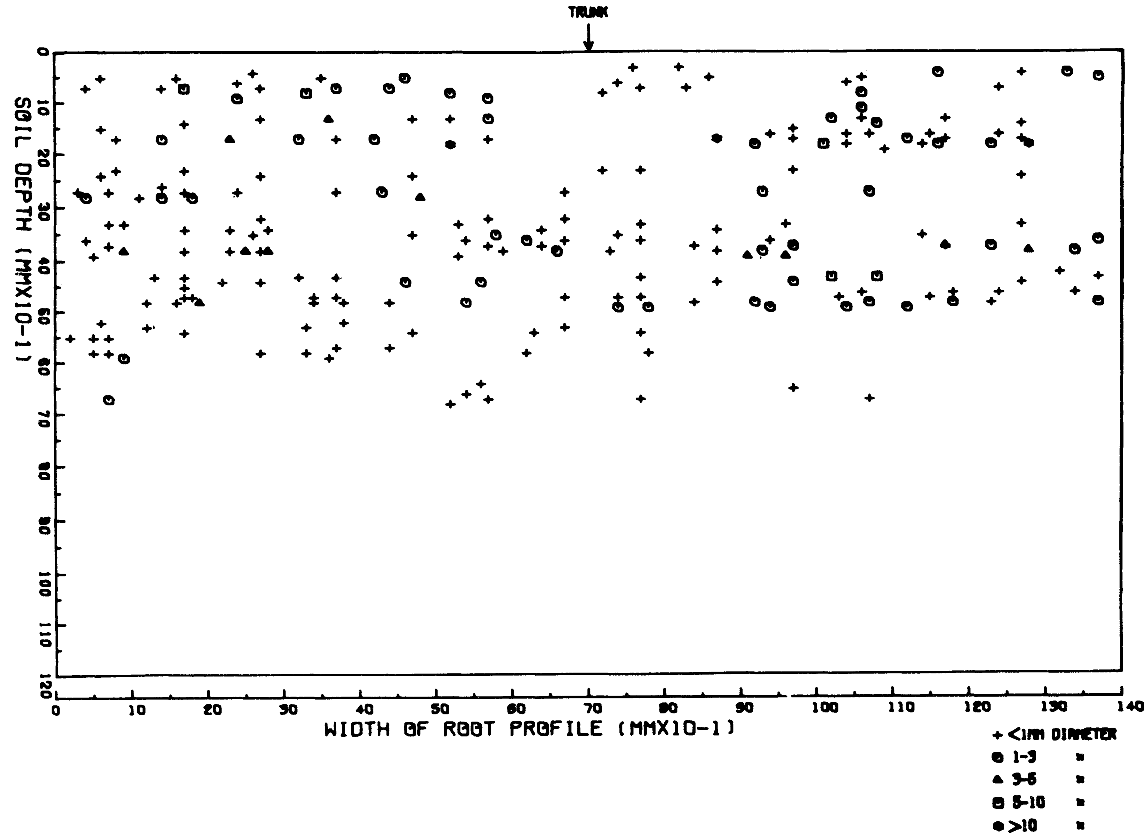

Fig. 3. Root distribution on Devon series in Aug. 1977 for the 15% SWD level.

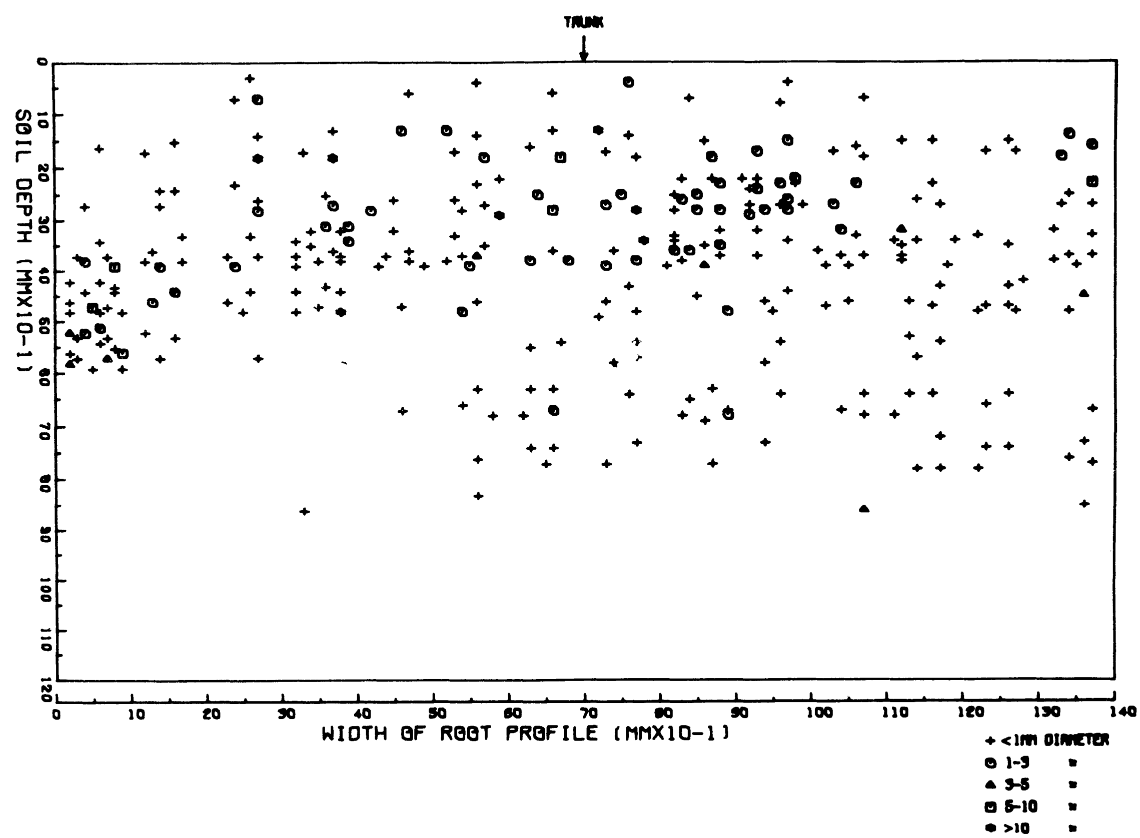

Fig. 4. Root distribution on Devon series in Aug. 1977 for the 75% SWD level.

Table 3. The total percentage of roots per depth increment on soil types.

Depth increment (mm)	Roots ± SE on Dundee form (%)[z]		Roots ± SE on Devon series (%)[z]	
	SWD level			
	15%	75%	15%	75%
0 – 100	14.9 ± 2.5	7.1 ± 1.6	11.7 ± 1.3	6.6 ± 3.2
100 – 200	10.4 ± 0.6	6.3 ± 2.4	15.5 ± 0.5	11.1 ± 0.7
200 – 300	8.0 ± 1.4	7.2 ± 1.1	11.5 ± 0.3	18.4 ± 2.6
300 – 400	16.3 ± 2.7	10.8 ± 1.4	17.6 ± 3.2	21.3 ± 2.4
400 – 500	20.2 ± 3.5	11.9 ± 1.6	19.2 ± 1.5	13.5 ± 0.3
500 – 600	18.2 ± 2.5	14.4 ± 3.2	10.7 ± 0.3	7.7 ± 0.8
600 – 700	6.4 ± 1.5	12.9 ± 2.5	5.8 ± 1.3	4.8 ± 1.7
700 – 800	4.8 ± 1.7	11.4 ± 0.6	2.4 ± 1.4	5.6 ± 1.2
800 – 900	0.7 ± 0.1	9.7 ± 2.8	2.7 ± 1.6	6.2 ± 2.8
900 –1000	0.0	8.2 ± 2.0	2.9 ± 1.7	4.7 ± 2.4
F values[y]				
0–600	27.5*		6.8	
600–1000	27.5*		6.8	

[z]Means of 1977, 1978, and 1979.
[y]F (P = 0.1) = 8.5.
*Significant at P = 0.05.

in the top 600 mm of soil for the wet treatment (Fig. 1). In effect, the water extraction depth of 700 mm for the 1978–79 season excluded 7.7% roots found in the Aug. 1978 studies (data not included).

In contrast, under the dry treatment, root development extended down to 1100 mm in Aug. 1977, but density decreased (Fig. 2). The means in Table 3 show that the 600–1000 mm soil profile contained 42.2% of the roots, which was significantly higher than the wet treatment. A water extraction depth of 1100 mm was chosen for the dry treatment for the 1978–79 season.

The apparently infrequent occurrence of roots in the top 200 mm of soil for the wet treatment (Fig. 1) could be due to soil physical and chemical resistance to root penetration. A relatively high bulk density of 1.56 g cm^{-3} (Table 4) was measured at 150 mm depth on this particular plot, while a below-optimum pH-value of 4.3 was measured at the same depth. Both conditions are unfavorable for root development.

Devon series (loam). In the 0–600 mm soil layer, the wet treatment (15% SWD), in accordance with the Dundee form, gave the higher concentration of roots of the 2 depletion levels compared. This soil layer had a mean root content of 86.2% for the wet, compared to 78.6% for the dry treatment (75% SWD). The difference approaches significance at a 10% confidence level (Table 3). Figs. 3 and 4, in effect, show some dissimilarity in distribution patterns for the 2 depletion levels.

Table 4. Bulk densities of typical plots of 2 soil types.

Depth (mm)	Bulk density (g cm^{-3})			
	Dundee		Devon	
	SWD level			
	15%	75%	15%	75%
150	1.56	1.50	1.64	1.67
300	1.49	1.50	1.53	1.60
450	1.30	1.32	1.57	1.61
600	1.43	1.35	1.61	1.59
750	1.47	1.34	1.54	1.65
900	1.44	1.36	1.68	1.67
1050	1.42	1.40	---	---

The loam (Devon series) under the dry treatment developed more roots with depth than the wet treatment, although not to the extent found in the loamy sand (Dundee form). Table 3 shows that the 600–1000 mm soil layer contained 21.3% of the total roots for the dry treatment compared to 13.8% for the wet treatment. The difference approaches significance at a 10% confidence level. Treatment effects on the Devon series were probably diminished by high soil bulk densities. While soil pH was favorable for root growth at 4.7 in the 0–750 mm layer, bulk densities were 1.67 and 1.64 g cm^{-3} at 150 mm depth for the wet and dry treatment plots, respectively. Mean bulk densities in the 0–300 mm layer were 1.63 and 1.59 g cm^{-3}, respectively (Table 4).

A water extraction depth (WED) shallower than the actual rooting depth also was chosen for the Devon series. A WED of 700 mm in the 1978–79 season for the wet plots included 92.0% roots (Aug. 1978 studies). For the dry plots, the chosen WED of 900 mm included 93.6% roots found in the Aug. 1978 studies (data not included). By delimiting a shallower irrigation depth than the actual rooting depth, deep drainage, as well as leaching of nutrient elements out of the root zone were practically zero. This technique of restricting drainage losses also was employed by Shalhevet and Bielorai (5).

Discussion

Root diameter was less affected by the soil water regime on the Dundee form (loamy sand) than on the Devon series (loam). On the latter soil type, a reduced proportion of small roots (< 1 mm) was found for the wet treatment. This reduction could be due to high soil bulk density in the top soil layer of the Devon series.

On the Dundee form, a marked difference in root distribution was effected by the 2 extreme soil water regimes. For the wet plots, intensive root development was confined to the top 600 mm of soil, while a much sparser root system, extending down to 1000 mm, developed for the dry plots. These findings agree with those of Levin et al. (2) who reported that a high irrigation frequency applied to the 0–600 mm soil layer caused a relatively dense and shallow root system. They also found that a low irrigation frequency produced relatively poor root development in the upper soil layers, but more roots developed in the deep layers.

Irrigation at different soil water levels had a less dramatic effect on root growth and distribution with depth on the Devon series than on the Dundee form. Certain soil factors must have played an important role in producing a much sparser root system on the former than on the latter soil type. With the soil pH being favorable on the Devon series, the most probable alternative factor restricting root growth was high soil bulk density. Mean bulk densities were 1.65 and 1.61 g cm^{-3}, respectively, in the 0–150 mm and 0–900 mm soil layers. On the Dundee form, the respective densities were lower, viz 1.51 and 1.42 g cm^{-3}.

Taylor and Gardner (6) found that for a fine sandy loam, bulk densities higher than 1.65 g cm^{-3} impeded penetration of cotton taproots. Furthermore, at a given bulk density, taproots had a greater probability of penetrating soils at high soil water pressures that at low pressures. Using sandy loam to silty clay soils Zimmerman and Kardos (7) found that the entrance and growth of roots at a soil bulk density of 1.60 g cm^{-3} were limited. At a density of 1.80 g cm^{-3} the adverse effects were even more pronounced. All these findings support the observations reported in this paper.

A review of these data on the aspects of root size distribution leads to the conclusion that different soil water depletion levels affected rooting depth more than size differentiation.

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Growth and Development Responses of Geranium to Temperature, Light Integral, CO_2, and Chlormequat

J.W. White[1] and I.J. Warrington[2]
Plant Physiology Division, DSIR, Private Bag, Palmerston North, New Zealand

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Abstract. **"Red Elite" geraniums were grown from the 6th leaf stage until the visible bud stage in controlled environment (CE) chambers under 3 day/night temperature regimes (27°/13°, 23°/17°, or 20°/20°C) and under enhanced CO_2 (900 μl CO_2/liter air) at 27°/13°. Three daily light integral treatments, 24.6, 19.8, and 15.1 mol m^{-2} d^{-1}, were imposed over each of these 4 treatments. Plants also were grown in a 22°/14° glasshouse with 2 daily light integral treatments (18.2 or 11.3 mol m^{-2} d^{-1}). A chlormequat (CCC) drench was applied to half of the plants immediately before the treatments were started. For the period between the 6th leaf and visible bud stages, leaf area, leaf area ratio, specific leaf weight, shoot dry weight, leaf canopy height, and time to visible bud were determined mostly by daily mean temperature rather than by day or night temperature. Most plant growth characteristics, but not the flower bud development rate from 6th leaf to visible bud, were enhanced by supplemental CO_2 and suppressed by CCC. After reaching the visible bud stage, plants from some treatments were moved into 24°/15° CE temperature conditions with or without CO_2, whereas others were moved to a glasshouse until harvest at the 1st floret anthesis stage. Between visible bud and anthesis, CCC was the major factor affecting vegetative growth regardless of whether the plants were with or without supplemental CO_2 in CE rooms, or in a glasshouse. Anthesis was delayed by about 10 days in the glasshouse compared to the CE treatments but was unaffected by CO_2 or CCC treatments. Carbohydrate concentrations were highest (starch 14%, sugar 5%) in plant leaves grown with supplemental CO_2 and without CCC, and lowest with no added CO_2 but with CCC in all CE treatments. The concentrations were reduced (starch 0.5%, sugar 2.5%) in plant leaves grown in a glasshouse from 6th leaf stage to anthesis because of low daily light integrals and no supplemental CO_2.**

Geraniums are commonly grown with cool night (15°C) and warm day (21° to 23°) temperatures and thus require supplementary heating during the late winter and early spring (11). High fuel costs have stimulated the need to understand the physiological responses of geranium so that the management of temperature, light, CO_2, and growth regulators can be improved.

The influence of temperature has been studied previously by a number of workers, but these studies have used either asexually propagated cultivars (9), or have examined only constant (3) or night temperature effects on hybrid geraniums (4, 14). Further, these studies have examined the response to temperature either over the entire production period (4) or over the period from visible bud to flowering (3).

For purposes of this study, 3 growth phases were identified: sowing to transplanting (6th leaf stage), transplanting to visible bud (bud 1 cm diameter), and visible bud to flowering (1st floret at anthesis). Environmental factors can influence geranium growth and development differently during each of these phases. Daily light integral has been reported as being important particularly during the 6 weeks of development between transplanting and

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[1]Professor, Dept. of Horticulture, Pennsylvania State Univ., Univ. Park, PA 16802.
[2]Scientist, Plant Physiology Division, DSIR, Palmerston North, New Zealand.