ROOT LENGTH AND VAPOUR PRESSURE DEFICIT: EFFECT ON RELATIVE WATER CONTENT IN *ZEA MAYS* L.*

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This investigation was undertaken to answer the question: "does a plant grown under irrigated conditions really need an extensive root system?" Wiersum (1967) is of the opinion that plants do not need the extensive systems they could grow. The question was of great relevance to the irrigated areas in the Riverina of Australia where root penetration is a problem on dense clay soils.

A critical problem in the Riverina appeared to be the high potential evapotranspiration rates ($1 \cdot 0$ cm day^{-1}) which exist during the growing period (Downey 1971). Hence it was important to know what length and density of root was required to maintain active growth under these conditions. Gardner (1966) and Cowan (1965) predicted that when the average soil matric potential (Ψ_τ) was greater than -100 J kg^{-1}, resistance to water movement in the soil (R_s) would be small. They also predicted that R_s would be influenced by root density although the values they used for root density were unrealistically low (Newman 1969). The experiment described below tested some of their predictions using maize (*Zea mays* L.) as an indicator plant.

Methods and Materials

The experiment was conducted under controlled environment conditions where root temperature could be maintained at 26 ± 1°C at all times. This is near optimum root temperature for maize (Beauchamp and Lathwell 1967) and by keeping the temperature constant problems associated with changes in root conductivity (Brouwer 1965) could be avoided.

A split root system was employed in which roots were trained into four, equal, polythene-lined sections of a 8-litre container. Each section was equipped with independent drainage. The principle was similar to that used by West, Thompson, and Black (1970) with apple trees. The rooting medium was quartz sand (mean particle size $0 \cdot 4$ mm) and $0 \cdot 25$ strength Hoagland's solution was used as nutrient (supplied daily).

Eight plants, selected for uniformity at the 10-leaf stage (about $0 \cdot 6$ m high) were allowed to deplete their water supply until near permanent wilting point. Ψ_τ, monitored with electrical resistance blocks (Hughes 1966), was $\approx -10^3$ J kg^{-1} in all sections. Half of the plants were re-irrigated in all sections; the other half were re-irrigated in only one section. After 7 days the plants had recovered and were growing normally. They were then placed in a controlled environment chamber of the L.B. type (CSIRO Irrigation Res. Lab. Rep. 1963, 1964) and subjected to changes in atmospheric demand.

Atmospheric demand was varied by changing air temperature in four steps between 15 and 45°C in the order 25, 35, 15, 45°C. Relative humidity was measured using wet and dry bulb thermometers and the vapour pressure deficit (VPD) was calculated for each temperature. Prasad (1969) has shown that, of the environmental factors net radiation, evaporation, VPD, wind movement, and air temperature, VPD is the single most important factor in determining relative water content (RWC). Light flux density throughout the experiment was maintained at $0 \cdot 22$ cal cm^{-2} min^{-1}.

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Measurements of RWC were made on the two uppermost mature leaves of each plant at all levels of VPD. Six disks, 0·8 cm in diameter, were taken per plant at each sampling; the method used has been described by Slatyer and Barrs (1965) with a correction for temperature (Millar 1966). Errors in RWC due to endogenous rhythms would be included in the experimental error.

When the above was completed, the four plants, previously re-irrigated in all sections, were again permitted to deplete their water supply until Ψ'_τ was less than -10^3 J kg^{-1} in all sections. These plants were then subjected to the four levels of VPD, and RWC was again measured. This procedure was repeated for all treatments with stressed sectors in the root system except that the roots were cut and not just stressed. Cutting the roots was simply a check that the stressed root system was indeed ineffective. In the above way it was possible to vary the effective root length without destroying part of it. At the conclusion of the experiment the roots were removed from each section and their length measured using the line intercept technique (Newman 1966).

Results and Discussion

The results presented in Figure 1 show that even when Ψ'_τ was maintained at field capacity a severe atmospheric demand (VPD > 70 mb) caused a significant drop

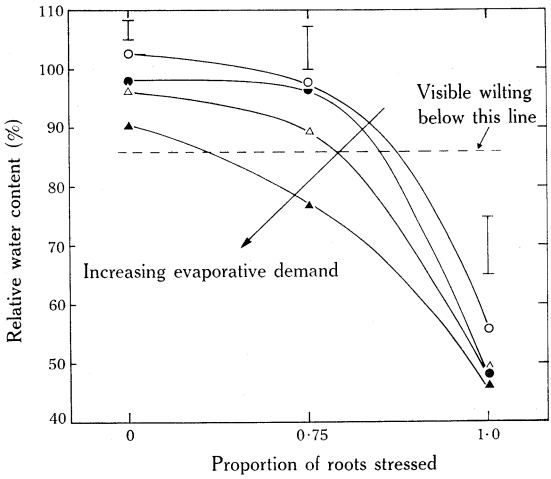

Fig. 1.—Relationship between the proportion of roots stressed to less than -10^3 J kg^{-1}, relative water content, and vapour pressure deficits (mb) of 0–3 (○), 10–14 (●), 33–36 (△), and 71–79 (▲) in *Z. mays*. Vertical lines indicate least significant differences at $P < 0·05$.

in RWC. That is, there was a lag between transpiration and absorption. This was predicted by Phillip (1957). Other work predicted appreciable resistance to water flow between the soil and the root surface but mainly with much lower soil matric potentials (Cowan 1965; Macklon and Weatherley 1965; Gardner 1966). Recently, Lang and Gardner (1970) demonstrated this resistance with cotton. Other work has shown that the plant resistance to water flow is not constant but declines as the rate of transpiration increases.

There are two possible explanations for the drop in RWC; one is that the plant resistance reaches a limiting value; the other is that appreciable rhizosphere resistances (R_s) arise even with $\Psi'_\tau \approx -10$ J kg^{-1} and root densities of 4·4 cm cm^{-3}. Probably both mechanisms play a role but it is beyond the scope of this communication to speculate on the magnitude of the resistances involved.

A further point of interest is that at low (3·0 mb) VPD, values of RWC greater than 100% were obtained. Other workers have presented similar findings (Lemon 1966; Burrows 1969) but have not commented on them. In the present instance it is felt that the anomaly is not due to experimental error. It is postulated that with atmospheric temperature (15°C) lower than soil temperature (26°C), root pressure (Barrs 1966) contributes significantly to leaf water potential in the intact plant. Guttation is the normal expression of this contribution but was not observed. Cutting the leaf disks removes the effect of root pressure (which can be as high as +600 J kg^{-1}) (Barrs 1966). Hence, when the disks are floated on pure water they lose water in coming to equilibrium.

When only 25% of the root system was maintained at field capacity (actual effective root length from Table 1, 9×10^3 cm) the plants were unable to maintain

TABLE 1

ROOT LENGTH AND DENSITY PARAMETERS

Proportion of Roots Stressed	Total Root Length (cm)	Root Density (cm cm^{-3})
Nil	3×10^4	4·4
Three-quarters		
Stressed section	2×10^4	3·8
Unstressed section	9×10^3	4·5
All	3×10^4	4·4

turgidity at a VPD greater than 40 mb. (Maize wilts over a range in RWC between 90 and 83%—Downey and Miller 1971.) With a lower evaporative demand (0–14 mb) a large root system was no advantage because 9×10^3 cm of root at $\Psi_\tau \approx -10$ J kg^{-1} was sufficient to maintain turgidity. It made no difference whether the roots were cut or simply maintained at a low Ψ_τ because the regression equation

$$y = 0\cdot88x+7\cdot9,$$

where y = RWC when 75% roots were stressed and x = RWC when 75% roots were cut, accounted for 85% of the variation between the two treatments (cut and stressed). The slope of this line did not differ significantly from the 1 : 1 line—indicating that the stress treatment successfully rendered 75% of the root system inactive.

With Ψ_τ less than -10^3 J kg^{-1} in all sections of the root system, RWC was severely depressed. This was true for all plants even at low levels of VPD. Hence a total root length of 9×10^3 cm, at a matric potential of -10 J kg^{-1}, maintained *Zea mays* above wilting until the vapour pressure deficit rose to 40 mb. A larger root system (3×10^4 cm) was required to maintain turgidity when the vapour pressure deficit was greater than 40 mb.

It follows that when VPD is very high (71–79 mb), a plant with a small root system cannot supply water as fast as it is transpired. Days with a VPD greater than 80 mb do occur at Griffith, N.S.W., where this work was completed. The conclusion to be drawn is that in conditions of high evaporative demand there *are* advantages in having a large root system.

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