SHORT COMMUNICATIONS

A GROWTH ANALYSIS OF THE YOUNG SORGHUM ROOT SYSTEM*

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Abstract

Root systems of sorghum plants grown in soil were measured at 9, 14, and 17 days from sowing. Data for 10 parameters of the root systems are reported. Notable features of the results were the low average diameter of the root members (*c.* 0·2 mm) and the very high mean extension rate (*c.* 0·8 cm per member per day), which was five to eight times higher than values reported for barley.

Despite the rapid root development, sorghum tended to maintain stable relationships between the overall number, length, surface area, and volume of its root members, as do other species.

Introduction

Accounts of several aspects of sorghum root development are now available in the literature. For example, Freeman (1970) described the morphology and anatomy in broad terms, Miller (1916) reported on horizontal and vertical spread, and Lavy and Eastin (1969) examined the relative phosphate absorbing capacity at different depths. So far, however, no morphological growth analysis appears to have been attempted. Such analyses can be helpful in interpreting root performance (Barley 1970), and with the aim of providing information of this nature, young root systems were measured at three times from sowing. This communication summarizes the results and makes comparisons with published data for other species.

Materials and Methods

The root material was obtained from an experiment of Mr. H. A. Nix and Mr. D. G. Morris, designed to study dry matter partitioning in sorghum under two temperature regimes. Due to partial breakdown in control, the glasshouses used to create the treatments operated at similar temperatures, and for the purposes of the present paper the two populations of plants will be treated as one.

Seed of a hybrid grain sorghum [*Sorghum bicolor* (L.) Moench. cv. Texas RS-610] was sown in Canberra on 10 January 1972. The root medium was fine sandy loam held in 10-cm-diam. plastic drainage pipe 100 cm long and sealed at the bottom. The soil was packed to a bulk density of about 1·3 g cm^{-3}. Nutrient solutions were applied to the soil on day 0 and day 10 at the rate (mg per plant) of 55 nitrogen, 35 phosphorus, and 129 potassium, and water was applied as necessary to maintain the pots at field capacity. Ambient temperature ranged between 29 and 35°C during the day, and between 18 and 24°C at night. Root temperature was maintained at 29–34°C by circulation of water around the cylinders of soil. This temperature was higher than desired, but the root systems

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grew vigorously nevertheless, and the possibility that the results are atypical for sorghum is thought to be remote.

In all, 16 plants per day were harvested on days 9, 14, and 17 from sowing, 10 of these being used to obtain root dry weight. Most of the soil was first washed away, then the roots with adhering soil particles were dried and weighed. This material was then ashed and a soil-free root weight estimated, assuming the roots to have the same ash content as the stem, namely 7%. Possible errors in this assumption could have an effect of only ±3%.

To determine other root characteristics on day 9, the remaining six root systems were also washed out entirely and were placed in formalin–acetic acid–ethanol preservative (Johansen 1940). Root arising from the mesocotyl (henceforth called mesocotyl root) was kept separate. At the other two harvests, the soil from the six cylinders was well wetted and then extruded from the tube by applying air pressure at the base of the column. Six sample 5-cm slices of soil were taken from points down the column, and the root material therein was washed out, again with the mesocotyl root kept separate. (This sampling procedure was adopted merely to save labour. Determinations of root density profiles would not have been meaningful because of the horizontal constriction of the root system, although roots did not accumulate around the surface of the columns.)

Root length was determined by the Newman method (Newman 1966), using the grid system devised by Marsh (1971). The number of root apices was determined by weakly staining the root material with acetocarmine, spreading over Marsh's grid, and counting the apices which appeared red (any grid spacing would have been suitable for this operation). For the determination of root diameter, the material was first chopped into lengths of about 1 cm. The pieces were then placed in water and a sample collected while the water was being vigorously mixed. The sample was spread on a small portion of Marsh's grid, and the diameter of pieces intersecting the lines was recorded by use of a microscope. In this way an average diameter ($\bar{d}$) was obtained which was weighted according to the length of each type of root member present (Hackett 1968). Except for the lowest depths, where insufficient material was available, 40 determinations of diameter were made for each depth from each replicate cylinder. To calculate $\bar{d}$ for entire root systems, the sum of the lengths at each depth (after allowance for sampling) was divided into the sum of the products of diameter and length at each depth.

Results and Discussion

The shoot development of the plants up to 17 days is summarized in Table 1. The rate of stem extension and the rate of increase in dry weight was high, as is characteristic of sorghum.

TABLE 1

SHOOT SYSTEMS OF THE SORGHUM PLANTS WHOSE ROOT SYSTEMS ARE DESCRIBED IN TABLE 2

Values in parentheses are standard errors as percentage of the mean

Measurement	Days from sowing					
	9		14		17	
No. of visible leaves on main stem*	3·8	(2)	5·6	(1)	7·7	(2)
No. of tillers	0·0	—	0·5	(36)	1·1	(18)
Total leaf area (cm²)	16·6	(10)	111·5	(5)	395·9	(7)
Total leaf dry weight (g)	0·046	(9)	0·324	(6)	0·842	(11)
Stem dry weight (g)	0·030	(7)	0·259	(8)	0·565	(14)
Height of canopy (cm)	17	(4)	27	(3)	42	(3)

* Stem = leaf sheaths; leaf = leaf blades.

Table 2 summarizes the root measurements. It was notable that there were 11·4 m of root on day 9 and 143·0 m by day 17 (0·32 m m^{-1} day^{-1}). These values

make a striking comparison with ones for barley [4 m at day 14, 50 m at day 28, 0·19 m m^{-1} day^{-1} (Hackett 1968, 1969)] and for wheat [8 m at day 14, 30 m at day 21, 0·19 m m^{-1} day^{-1} (Passioura 1972)]. Despite the rapid rate of increase in total length, the average root length $\bar{l}$ (total length/total No.) remained roughly constant, as has been observed in other species (Hackett 1971). The values of $\bar{l}$ were about 75% higher than the average of those for barley (May *et al.* 1965; Hackett 1969, 1971).

TABLE 2

ROOT SYSTEMS OF SORGHUM PLANTS AT THREE TIMES FROM SOWING

Values in parentheses are standard errors as percentage of the mean

Measurement	Days from sowing					
	9		14		17	
Total No. of root members	455	(18)	2123	(12)	5371	(23)
Total length (cm)	1141	(12)	4926	(11)	14305	(24)
Average length, $\bar{l}$ (cm)	2·70	(14)	2·35	(5)	2·67	(8)
Average diameter, $\bar{d}$ (mm)	0·167	(6)	0·212	(4)	0·200	(3)
Total surface area (cm^2)*	58·8	(9)	331·5	(14)	864·5	(21)
Total volume (cm^3)*	0·245	(10)	1·88	(16)	4·45	(22)
Total dry weight (g)	0·056	(6)	0·226	(14)	0·509	(12)
Dry weight : fresh volume ratio (g cm^{-3})	22·9		12·0		11·4	

* Calculated from measurements of length and diameter assuming the root members to be smooth cylinders. No allowance for root hairs.

The value of $\bar{d}$ was smaller at day 9 than later, but the agreement between the values at the last two harvests suggested that $\bar{d}$ was stabilizing, as has also been observed in other species (Hackett 1971). Because $\bar{d}$ in the sorghum plants was of the order of 0·2 mm, the total root length occupied only 0·2 and 4·4 cm^3 at days 9 and 17 respectively. The dry weight : fresh volume ratio was fairly high initially but then appeared to settle at about 12%.

Further comparisons between the dimensions can be made by calculating the total length using approximate values to convert from dry weight, as is feasible when $\bar{d}$ and percentage dry weight stabilize (Hackett 1971). Taking the root dry weight of 0·5 g on day 17, and letting $\bar{d} = 0{\cdot}2$ mm and percentage dry weight = 10, one obtains 160 m as the estimate of total length, compared with the measured value of 143 m.

Using the method of calculation of May *et al.* (1965), the mean extension rate (MER) of the root members was found to be 0·70 and 0·89 cm per root member per day during the two periods of observation. These values are five to eight times higher than those found in barley (May *et al.* 1965; Hackett and Rose 1972*a*). Since the value of $\bar{d}$ in sorghum is similar to that found in barley (Hackett 1969), the high MER in sorghum must be principally responsible, morphologically speaking, for the high growth rate of the root system. It would be interesting to know whether such MER are characteristic of C_4 grasses. Also, since in barley the rate of extension is roughly related to the square of the diameter (Hackett and Rose 1972*b*), it would be interesting to know how, anatomically, sorghum achieves the high MER. The

kinetic method of analysing cell extension and proliferation in root meristems (Van't Hof 1967) could be applied to determine this.

Two further points deserve mention. The primary data for root diameter were analysed to see whether they fell into distinct populations, which might correspond with different orders of laterals. The graphs showed only one peak, at a diameter just lower than the calculated $\bar{d}$; then followed a long tail stretching to about 0·35 mm and continuing irregularly thereafter according to the number and diameter of root axes present.

The second point relates to the mesocotyl root. This root material differed in origin and form from that which arises near the coleoptile node in wheat and barley (Taylor and McCall 1936; Hackett 1968). The axes of the latter roots grow downwards from close to the seed and are difficult to distinguish externally from the seminal axes. The mesocotyl root in sorghum emerged well above the seed and grew out horizontally from a variety of points along the mesocotyl. The roots were fine (generally $< 0 \cdot 20$ mm) but had a similar $\bar{l}$ to that of the entire root system. Their most striking characteristic was their variable development. The replicate values for the ratios of length (cm) of mesocotyl root to that of total root in the 0–5-cm slice at day 14 were 1863 : 3115, 10 : 3544, 60 : 2505, 1002 : 2560, 0 : 1637, and 639 : 3069. The variation in length of mesocotyl root appears to be compensated for by root growth from other points (or vice versa), but whether functional compensation occurs is unknown.

Apart from yielding new information about root development in sorghum, this study demonstrated that many parameters of importance in the growth analysis of root systems can be determined from soil-grown plants.

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