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Assessment of Genotypic Differences in Sorghum Root Characteristics

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Summary

Representative data on genotypic differences in sorghum root characteristics are examined for prospective use in applied breeding programmes. Significant genotype differences in root characteristics observed are: root-length density at lower depths when the crop is grown on stored soil moisture, root-shoot ratios, early establishment of nodal roots in seedlings, and microbial associations of roots. Four-fold genotypic differences in root-shoot ratio were found at the seedling stage, but high ontogenic shifts negated these differences at later stages. Hence sorghum breeding for efficient root systems should be confined to well-defined target environments with specific objectives.

Introduction

Genotypic variation in root characteristics are believed to be as large as those in shoots (Bohm, 1979). O'Toole & Bland (1987) have reviewed genotypic differences in root characteristics of annual crops including sorghum (*Sorghum bicolor* (L.) Moench). Quantification of genotypic difference in root characteristics in the field is difficult, and most often the results obtained are not commensurate with time and resources spent. Root growth of field crops is highly variable depending upon the edaphic factors, cultural practices, and seasonal weather conditions. Furthermore, measurements on roots independent of the shoot or the edaphic environment are of little direct practical consequence in agriculture. Hence, in spite of the efforts for gaining a complete understanding of the root system throughout crop growth, to be cost-effective, most studies are aimed at specific events or processes at predetermined crop growth stages so that shifts in sinks, source, as well as the other site-specific factors limiting production, can be taken into account while interpreting the data (Mirhadi & Kobayashi, 1980).

The objectives of this paper are to examine: (1) the genotypic differences in root characters of sorghum, and to evaluate its significance for crop adaptation or better performance with specific sets of genotypes (such as genotypes differing in their response under particular pattern of drought or soil fertility), and (2) the prospects of using such genotypic variation for better performance under stress conditions. Only representative data selected from different experiments are reported here to illustrate variations in individual root characteristics.

Materials and Methods

Experiment 1

Seven sorghum genotypes were grown on stored moisture on Vertisols in large plots (10 x 15 m) during the postmonsoon season. Soil cores (76 mm diameter) were

Table 1. Time to 50% flower, root-length density (RLD) at mid-grain filling stage, and water-use efficiency (WUE) of sorghum genotypes grown during postmonsoon season (Expt 1)

Genotype	Time to flower (days from sowing)	Mean RLD (cm cm^{-3})		WUE (t m^{-1} ha^{-1})
		A. Surface -1.5 soil profile	B. 1.2-1.5 m profile only (B as % of A)	
I_0: Dryland crops (profile water content at flowering = 0.1 m)				
Terminal drought resistant genotypes				
NK 300	54	0.229	0.280 (20.4)	40
CSH 6	61	0.247	0.231 (15.6)	41
CSH 1	66	0.246	0.259 (16.2)	42
CSH 8	67	0.302	0.303 (16.9)	48
SPV 86	75	0.262	0.513 (32.7)	53
Terminal drought susceptible genotypes				
CSV 5	69	0.327	0.270 (11.0)	28
V 302	74	0.253	0.340 (22.4)	39
Mean	67	0.267	0.314 (19.3)	42
I_2: Crops with 2 irrigations before flowering (profile water content at flowering = 0.14 m)				
CSH 1	66	0.340	0.240 (12.1)	24
CSV 5	72	0.485	0.374 (13.0)	22
V 302	72	0.360	0.493 (16.0)	25
Mean	70	0.395	0.369 (16.0)	24

RLD = Root length per unit soil volume : cm cm^{-3}
WUE = Above-ground biomass per unit water and area : tonnes m^{-1} ha^{-1}.

taken to 1.5 m depth both on the ridges (crop row) and in the furrows randomly at 3 places in each plot, at 80 days after sowing (DAS) during the mid-grain filling period. The soil cores were divided into 0.1 m sections, repeatedly washed and the roots sieved out. Root-length density was determined by the method of Newman (1976). Grain and biomass yields were determined at harvest. Soil moisture was monitored periodically.

Experiment 2 — Six genotypes differing in resistance to early season drought were grown on ridges spaced at 0.6 m in Alfisol during summer. Irrigated (control), and stressed (no irrigation after 20 DAS) treatments were established after seedling emergence. Shoots of individual plants in each plot were cut 4 times during 9-37 DAS, and their roots excavated by coring. Roots were washed and dried along with shoots to determine their dry mass.

Experiment 3 — Four genotypes were grown on a wet, but rapidly drying Vertisol during the postmonsoon season. Seedlings were excavated at 11 DAS. The seminal and nodal roots were separated, counted, and their lengths measured. Dry mass of oven-dried plant parts was determined.

Experiment 4 — Sterile seedlings of 6 genotypes were grown in culture tubes in glasshouse (Wani, 1988). Growth medium was changed daily and organic carbon in the medium was estimated. Nitrogenase activity was estimated using acetylene reduction assay.

Experiment 5 — A set of 30 genotypes were sown in 3 Alfisol fields differing in native soil phosphorus (3.5-20 μg Pg^{-1} soil; Olsen's P). Genotypes were sampled at 40 DAS and analysed for mycorrhizal colonization as described by Krishna *et al.* (1985)

Results and Discussion

Genotypic Difference in Sorghum Root Systems During Grain Filling (Expt 1)

Crops receiving 2 preflowering irrigations (I_2) showed nearly 50% more mean root-length density (RLD) than unirrigated crops (I_0) (Table 1). The absolute size of the root system reflects more of the growing environment than its efficiency (Salisbury, 1988). However, the proportion of RLD at 1.2-1.5 m soil depth was less in I_2 than in I_0. The water-use efficiency (WUE) in I_2 was only half of I_0. Genotypic differences in mean RLD were low, but the differences in RLD at the lowest depth (more relevant to crops during terminal water stress) is evident. In the I_0 treatment, drought resistant genotype SPV 86 had twice as many roots at 1.2-1.5 m than in the susceptible CSV 5 (3 times as many, when expressed as percentage of total roots per plant). Thus it appears that use of such genotypic differences in RLD during the critical stage of grain filling, in terminal stress environments, is useful for increasing WUE (Seetharama *et al.*, 1984).

Table 2. Changes in root-shoot ratios of drought resistant and susceptible genotypes (Expt 2)

	Days after sowing			
	9	16	23	37
A Wet Treatment (irrigation at 7 days interval)				
Drought resistant genotypes				
ICSV 213	0.667	0.349	0.113	0.064
SPH 263	0.932	0.415	0.103	0.058
IS 22380	0.755	0.260	0.124	0.064
IS 13441	0.615	0.384	0.126	0.055
Mean	0.742	0.352	0.117	0.060
Drought susceptible genotypes				
IS 12739	0.392	0.210	0.121	0.062
IS 12744	0.481	0.186	0.080	0.066
Mean	0.437	0.198	0.101	0.064
Mean for 6 genotypes	0.640	0.301	0.111	0.061
SE ±	0.079	0.039	0.007	0.001
CV (%)	30.200	31.700	15.700	6.500
h^2	0.300	0.420	0.130	0.100
B. Dry treatment (no irrigation from 20 DAS)				
Mean for 6 genotypes	0.657	0.323	0.114	0.059
SE ±	0.081	0.054	0.006	0.002
CV (%)	33.200	41.100	13.100	6.400
h^2	0.300	0.160	0.110	0.060
Level of significance of genotype differences (P)	0.016	0.120	0.111	0.796

Root-Shoot Ratios of Genotypes Differing in Resistance to Early-Season Drought (Expt2)

The root-shoot relationships during plant growth are dynamic and are markedly influenced by the environment. The relationship between growth of shoots and roots is less complex in early stages of plant growth than in the late and reproductive stages (Troughton, 1981).

Mean root-shoot ratios under 2 irrigation regimes were nearly same at all stages, although numerically high at 9 and 16 DAS (Table 2). However relation between genotypes, irrigation levels and growth stages were not significant.

Genotypic differences in root-shoot ratio ranged from nearly 240% at 9 DAS (highly significant; $P>0.001$) to negligible at 37 DAS ($P<0.80$). About 160% higher root-shoot ratio of the drought resistant genotypes over the drought susceptible genotypes, evident at the two early stages (9 and 16 DAS), was reduced to insignificance at 23 and 27 DAS, irrespective of the treatments imposed.

The broad-sense heritability estimates (h^2, genotypic variance expressed as fraction of total variance) were low, and generally decreased at later growth stages. The estimated h^2 in the wet treatment was equal to or higher than that in the dry treatment.

The above results suggest that it is difficult to use root-shoot ratio of field grown crops as a criterion for screening genotypes for drought resistance. However, high root-shoot ratio in young seedlings may be useful in promoting seedling vigour in dry and nutrient poor soils, its reduction during later stages will ensure minimum investment of dry matter into roots so as not to compete with grain formation.

Genotypic Differences in Traits Related to Root Growth and Microbial Associations (Expts 3-5)

Rapid Establishment of Nodal Root System in Drying Soil (Expt 3) — Early initiation of nodal roots results in efficient uptake of water and nutrients from the top-soil layers. More genotypic variation is found in length and number of nodal roots than in their mass per seedling (Table 3A). Similarly, h^2 estimates were higher for nodal root related parameters than those for shoot or root-shoot ratio. Significant differences among genotypes were evident in the rate of development of nodal roots (length and number).

Sorghum Roots and Microbial Associations (Expts 4, 5) — Soil-plant-microbe interactions are related to complex environmental variables. Variations among host genotypes in their ability to stimulate both bacteria associated N_2 fixation (Table 3B), and mycorrhizal colonization were examined (Table 3C).

About 2-fold variation in the production of root exudates, and more than 4-fold differences in associative N_2 fixation were recorded but the quantities involved were too small to consider these parameters in breeding programmes (Table 3B). The variations between genotypes, as well as h^2 estimates, are higher for root and shoot dry mass than for root-shoot ratio.

Similarly, 2- to 3-fold variations in the percentage of root colonization by mycorrhizae in genotypes grown on low amounts of phosphorus were found. However, the amount of variation differed with soil P levels and location (Table 3C). The h^2 estimate for symbiotic mycorrhizal association was found to be higher than that for associative bacterial association.

Conclusions

The response of root system to variations in natural growth conditions is perhaps the most difficult aspect of plant behaviour to predict. Ontogenic shifts, low or inconsistent heritability, and expression in sufficient magnitude under narrow range of environmental conditions make it difficult to breed for desired root characteristics. Breeding for improved root systems is further compounded by the changing weather patterns of a particular region and the variability of moisture and nitrogen content in the soil profile. Hence more studies on phe-

Table 3. Genotypic variations in traits related to root production, crop growth during early stages (Expt 3), and microbial associations of roots (Expts 4 & 5) and the broad-sense heritability (h^2) of these traits

Character	Range	Mean ± SE	h^2
A: Expt 3- Nodal root growth and development (4 genotypes; sampled 11 days after sowing in a drying Vertisol field)			
1. Total length of nodal roots (mm seedling $^{-1}$)	44.4 - 142.1	86.8 ±11.80	0.66
2. Number of nodal roots (no. seedling^{-1})	1.8 - 3.1	2.4 ±0.18	0.61
3. Dry mass of nodal roots (mg seedling^{-1})	2.8 - 9.1	5.4 ±0.7	0.66
4. Dry mass of total root system (mg seedling^{-1})	7.4 - 13.5	9.80 ±1.0	0.56
5. Dry mass of shoots (mg seedling^{-1})	51.2 - 73.0	59.8 ±5.2	0.43
6. Root-shoot ratio.	0.13 - 0.23	0.16 ±0.02	0.36
B: Expt 4- Root exudates, nitrogenase activity, root and shoot dry weights (6 genotypes. Items 1 and 2: tube cultures; Items 3-5: pot culture in glasshouse)			
1. Organic carbon in root exudates			
a. µg plant^{-1}	259.0 - 473.0	38.2 ±50.0	0.42
b. µg g root^{-1}	11.5 - 21.4	15.4 ±2.5	0.36
2. Nitrogenase activity (n moles C_2H_4 plant^{-1} h^{-1})	12.6 - 52.9	24.5 ±5.0	0.41
3. Root mass (g plant^{-1})	15.2 - 37.1	26.0 ±1.6	0.80
4. Shoot mass (g plant^{-1})	15.2 - 29.0	26.5 ±0.68	0.80
5. Root-shoot ratio	0.49 - 0.71	0.59 ±0.71	0.38
C: Expt 5- Mycorrhizal colonization (of 30 genotypes sampled at 40 DAS in fields)			
1. Percent root colonization in low P soils			
a. in 1982 (Olsen's P: 3.5 µg P g^{-1})	15.0 - 42.0	26.0 ±3.1	0.64
b. in 1983 (5.0 µg P g^{-1})	35.0 - 77.0	57.0 ±4.2	0.77
c. in 1983 (20.0 µg P g^{-1})	11.0 - 59.0	34.0 ±4.7	0.71

notypic plasticity may be conducted, and crop improvement efforts may focus on specific root growth pattern, best suited for well-defined edaphic niches, as suggested by Jordan & Miller (1980), and O'Toole & Bland (1987). In the long run quantitative studies on roots in relation to the plant and its environment will have an impact on understanding the crop behaviour, and in integrating plant-environmental interactions for hypothesizing plant ideotypes, as was done for wheat (Miglietta *et al.*, 1987).

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