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Study of the Root System of Local and Improved Sorghum Cultivars Grown in Mali

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Authors' contributions

This work was carried out in collaboration between all authors. Author CFBT designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AGD and AOT managed the analyses of the study and reviewed the draft. Author AT managed the literature searches, mentored team and translated the manuscript in English. All authors read and approved the final manuscript.

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ABSTRACT

Roots play a fundamental role in plant growth by supplying water and mineral to the stem and leaves. These underground organs are much less known than the aerial organs mainly due to the difficult access to the root systems in soil. In spite of this, only a few studies were conducted on roots. Given the importance of roots for plant growth, a better understanding of their functioning may help solve some issues such as water stress that can affect the performance of the crops. A total of 100 sorghum cultivars collected in the Sahelian zone of Mali an area receiving an annual rainfall of 200 to 600 mm, were used in a root characterization study. The plant materials were composed of 4 races and 5 intermediates sorghum races. Seeds of the entries were planted directly in PVC tubes of 1m containing soil and arranged in completely randomized design with three replications; in one planting date. Each tube was planted in a dugout ground to 50 cm deep.

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The tubes were distant of 0.50 m within each row and 0.75 m between rows. The trial was watered from the tap every two days until harvest. The results showed high variability among the varieties studied for root length and root density, with a root length reaching over 1.00m. The study did not identify any pattern in the root systems of the four races and their five intermediates races. However, there was a positive correlation between root length and density indicating an increase in root length correspond to an increased root density. The diversity found in the root system could be a basis for improving root architecture in breeding populations and the evaluation of the behaviour of the sorghum varieties with different root systems in water stress conditions.

Keywords: Root; system; cultivars; sorghum.

1. INTRODUCTION

Sorghum (*Sorghum Bicolor* [L.] Moench) is grown in rainfed conditions between the 400 and 1300 mm isohyets and in flood recession condition of several lakes. The importance of this cereal in Mali is felt much more through expansion of planted areas for the last two decades, as well as the growing use in the daily human diet. Yields are generally low in farmer's fields (893 kg/ha, [1] because the crop is widely cultivated in environments where abiotic and biotic stress are common and limit production. Sorghum is adapted to the difficult climatic conditions and poor soils of West Africa. In addition, it has a good level of tolerance to the major insects and diseases.

Indeed, it is well established that one of the major constraints for the production of sorghum is water deficiency. Water is the natural resource that limits most crop yield in agriculture [2]. Several research projects aimed at improving the productivity of sorghum [3,4,5,6,7]. These studies showed the existence of drought tolerant ecotypes in local sorghum germplasm. Thus, CSM 205 was identified to be tolerant to drought at the seedling stage, and CSM 63E at the post-flowering stage [5].

Many studies [7,8] showed that sorghum adaptation comes from the alignment of crop maturity length with the beginning and end of the rainy season. This is due to the photoperiod sensitivity of local ecotypes. It is an important phenomenon in African sorghums whose flowering is induced by a change in the nychthemeral cycle (alternation of day and night). Photoperiod sensitivity may belong to a separate group of drought tolerant traits not described by Lewit, which would enhance the best rainfall resources [9]. Thus, photoperiod sensitivity as a mechanism for adaptation in sorghum mitigates the effects of climate variability by improving both the production stability and the grain quality. It adapts sorghum to spread its water use during the maturity cycle (tolerance) and phenology (avoidance). Sorghum maintains its production potential even when rainfall is low or erratic. It was also reported for different plant species [10].

The roots play a fundamental role in the production of the plants. Plant water and mineral supply are assured by roots. However, the roots have other functions, namely anchoring on the substrate, serving as the nutrient reservoir, metabolism etc. Roots contribute in particular to the hormonal balance controlling the growth and functioning of the plant. Absorption of water and nutrients by the root is determined by the surface of the root system. The density of roots and their distribution during the growing season, and in the different soil horizons, are therefore of obvious interest for a better understanding of the use of nutrients by a crop [11]. A lot of germplasm characterization research has been reported on local and improved sorghum germplasm. Thus, photoperiod sensitivity, adaptability, resistance to insects and diseases, grain yield and yield components, etc. have been widely studied. However, only a few studies were conducted on sorghum roots. These underground organs are much less known than the aerial organs. This is, mainly due to the difficult access to the root systems in the soil [12].

In recent years Mali is facing problems related to insufficient and poorly distributed rainfall which led to a reduced production of rainfed crops such as sorghum and millet. Given the role of sorghum in food security in the country, the importance of roots for plant growth, a better understanding of their functioning may help to solve some issues such as water stress that can affect the performance of the crops [13]. Thus, this study was conducted to better understand the root system of Malian sorghum varieties and its relation with important adaptation traits.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was conducted at the Agronomic Research Station of Sotuba (SRA/Sot) in 2006-2007. The SRA/Sot is located on the left rive of the Niger River, 7 km from the city center of Bamako and covers an area of about 265 ha. The climate is of the Sudanese type with rainfall varying from 800 to more than 1000 mm (latitude 12°38', longitude $7^0$56' and an elevation of 320 m). The soil of the station is a silty clay and sandy clay. The annual temperature is between 20°C (January) and 42°C (April and may). The flora is dominated by trees and constituted essentially of thorny and essences of values such as Caicedrats (*Khaya senegalensis*), Nérés (*Parkia biglobosa*), Karités (*Butyrospermum paradoxum*) etc.

2.2 Plant Materials

The study looked at 100 sorghum cultivars including 87 local varieties from the Malian Sorghum Collection (CSM) of 1978 and 1982 and 13 improved varieties developed by the national sorghum program. The 87 local varieties from the CSM used in the study were collected in the Sahelian zone beneath the isohyets 400 to 600 mm of rain in Kayes and Koulikoro. Some varieties were collected in Timbuktu and Gao regions, located in the isohyets of 200 mm. The plant materials were composed of 4 races: Durra, Guinea, Caudatum and Bicolor and 5 intermediates races: Durra bicolor, Caudatum Bicolor, Durra Caudatum, Guinea Caudatum and Guinea Bicolor. The improved varieties included Guinea race, intermediate Guinea-Caudatum and Caudatum races.

2.3 Methodology

The 100 genetic materials were planted directly in PVC tubes of 1m containing soil and arranged in completely randomized design with 3 replications in one planting date. Each tube was planted in a dug out ground to 50 cm deep (Photo 1). The tubes were distant of 0.50 m within each row and 0.75 m between rows. The trial was watered from the tap every two days until harvest. The plants were thinned to one plant per tube. The equivalent of 100 kg of ammonia phosphate fertilizer per hectare (0, 314g per tube) and 50kg of urea (0, 157g per tube) were added. At maturity, the roots in each tube were recovered by moderate water jet into the two openings in the tube. A sieve was used to recover root residues which were broken off from the rest of the root system during the washing. After washing each root is measured immediately before drying. The measured root was first spread out in the sun for partial drying and then put in an incubator for total drying at 40°C for 24 hours. After drying the roots were weighed using an electronic scale.

Photo 1. Field trial at Sotuba research station, Mali

Data collection focused on:

- The root length, measured as the distance between the last node to the end tip of the root
- The root density. This parameter is calculated using the formula

$D = M/V$

Where M represents the dry weight of roots and V the volume of the tube.

$V = \pi \times R^2 \times h$

R represents the radius of the tube and h the length of the tube.

$R = D/2 = 20/2 = 10cm$

D = diameter of the tube

$V = 3.14\ (0.1)^2 \times 1m = 0.0314\ m^3$
$D = M/V$
$D = M/0.0314\ m^3$

The software used for the data analysis is the GenStat.

3. RESULTS

The statistical analysis showed significant differences between different varieties for root length (Table 1). The roots varied in length from 1.26 m to 0.26 m (Photo 2). The observed average length was 0.896 m. Variety 97ML 0337-IS (1, 26 m), 97ML 0106 (1.18 m) and 97ML 0219 (1.17 m) have the longest root contrary to the varieties: 97ML 1514 (0.31 m) and 97ML 1840 (0. 26 m).

Table 1. Results of the analysis of variance for root length

Source	df	SS	MSS	Variance	Fpr.	Significance	LSD
Varieties	99	11.66862	0.11786	3.73	< 0.001	HS	0.2865
Residual	179 (21)	5.66170	0.03163				
Total	278 (21)	15.31156					
CV %				19,8			

df: Degrees of freedom
SS: some of squares
MSS: Mean sums of squares
Fpr: Fisher probability value
HS: Highly Significant
LSD: Least significant differences of means
CV: Coefficient of variation

Photo 2. Root length variability among the varieties studied

The results showed that 33% of the varieties have a root length varying from 1.00 m to 1. 5 m (Fig. 1). A total of 54% of the varieties have a root length ranking between 0.70 m and 1.00 m. The root length between 0.70 m and 0. 40 m was observed on 11% of the varieties. Only 2% of the varieties showed very short roots that varied between 0.40 m and 0.10 m. The 5 longest root systems were found among the Guinea, Dura and Guinea-Caudatum races while the 5 shortest root systems belong also to Guinea, Durra, Guinea-Caudatum races.

The statistical analysis of root density showed that there are significant differences among the different varieties studied (Table 2). For this variable, the minimum observed was 300 g/m^3 and the maximum 4784 g/m^3. The observed average density was 2219 g/m^3. The most dense roots were observed in 97ML 1672 (5219 g/m3); 97ML 0277 (4784 g/m^3); 97ML 1615, (4653 g/m^3) and 97ML 1832 (4189 g/m^3) and the lowest densities at 97ML 1514 (845 g/m^3, 97ML 1840 (839 g/m^3) and Grinkan (300 g/m^3). The average root length and root density of different varieties are presented in Table 3 and that of the different races in the study in Table 4.

The results also showed that only 3% of the varieties studied showed a high root density varying between 5000 and 4000 g/m^3. Among the varieties, 14% had densities between 4000 and 3000 g/m^3; 42% between 3000 and 2000 g/m^3; 34% between 2000 and 1000 g/m3 and 7% between 1000 - 100 g/m^3 (Fig. 2). The 5 top dense root systems were found among the races: Guinea, Durra, Durra-Bicolor and Guinea-Caudatum. The lowest root density systems were measured in Guinea-Caudatum, Durra and Durra-Bicolor races.

This study of the root system of local and improved sorghum cultivars grown in Mali also showed that there is a correlation between the length and densities of roots. The coefficient of determination observed R^2 was 0.2368, with a regression line Y = 3026.4 x - 505.88 (Fig. 3). The correlation coefficient r ($r = \sqrt{R^2}$) is 0.4866. It can be concluded from this analysis that an increase in the length of the roots corresponds to the increase in the density of the roots of 48.66%. This result is comparable to that found by [14].

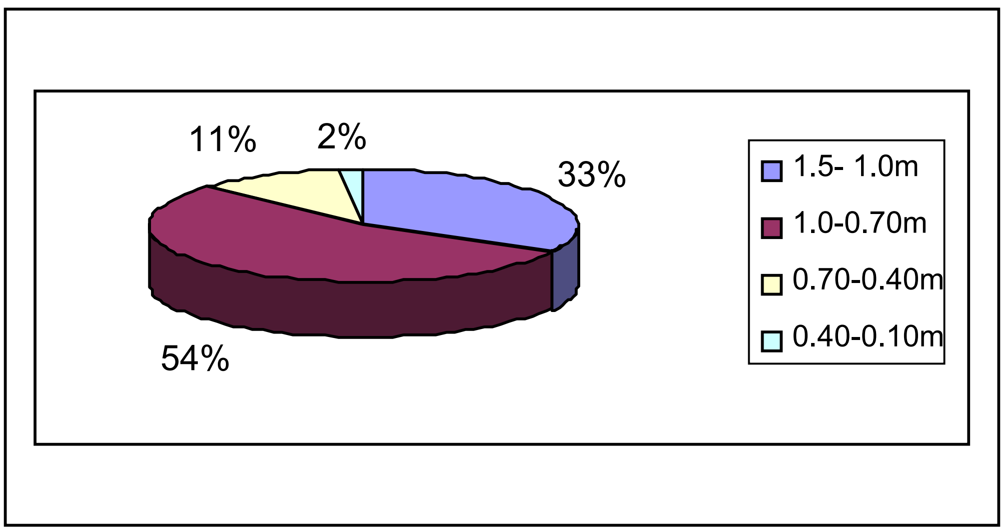

Fig. 1. Distribution of the length of the roots of the varieties studied

Table 2. Results of the analysis of variance for the root density

Source	df	SS	MSS	Variance	Fpr.	Significance	LSD
Varieties	99	189526864	1914413	3.94	<0.001	**	1302.1
Residual	146(54)	95064963	651130				
Total	245(54)	250883275					
CV %				36			

df: Degrees of freedom; SS: some of squares; MSS: Mean sums of squares; Fpr: Fisher probability value HS: Highly Significant; LSD: Least significant differences of means; CV: Coefficient of variation

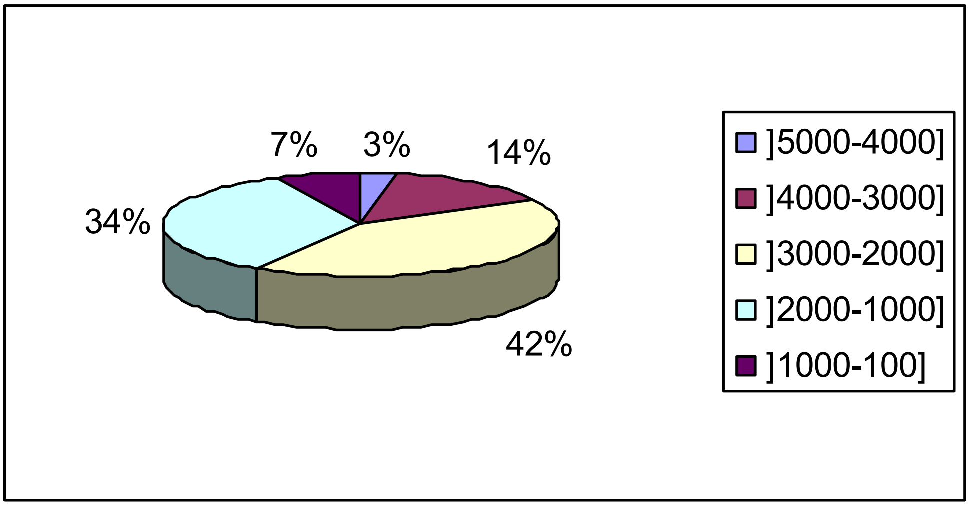

Fig. 2. Percentage of varieties according to root density classes (g/m^3)

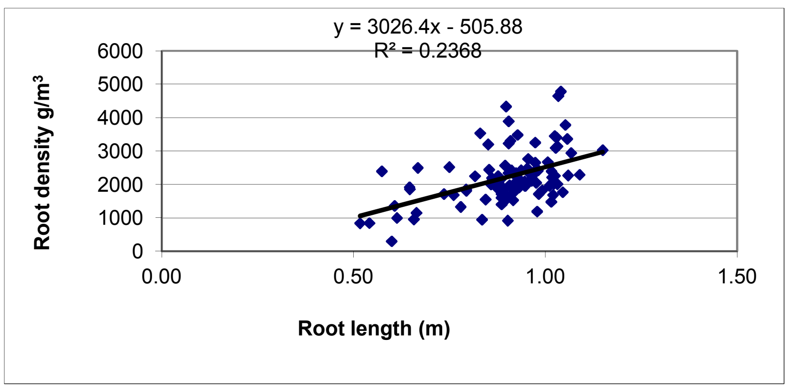

Fig. 3. Correlation between root length and rood density

Table 3. Average root length and root density of different varieties

Number accession	Variety	Root length	Root density	Village/Origin	Race
4	97ML0051	1.01	2659	BOLI	Bicolor
5	97ML0052	0.93	2960	BOLI	Caudatum
41	97ML0301	1.08	3095	YOURI	Caudatum
48	97ML0339	0.91	3228	KIRANE	Caudatum
91	GRINKAN	0.47	300	IER	Caudatum_Improved
93	M 84 1	0.72	1834	IER	Caudatum_Improved
95	98 SB F2 78	0.86	1496	IER	Caudatum_Improved
96	M 92 1	0.9	1583	IER	Caudatum_Improved
73	97ML1721	0.91	1981	ALFAO	Caudatum-Bicolor
16	97ML0181-IS	1.08	3453	DALI	Durra
17	97ML0183-OR	0.78	2356	SAMPAKA	Durra
8	97ML0152	1.02	2188	KONRONGA	Durra
9	97ML0156	0.92	2426	NARA	Durra
11	97ML0158	1	2304	NARA	Durra
13	97ML0160-IS	1.02	2421	SEGUE	Durra
19	97ML0188	1.07	2370	SAMPAKA	Durra

Number accession	Variety	Root length	Root density	Village/Origin	Race
23	97ML0197	0.84	1727	ASSAMAN	Durra
24	97ML0198	0.84	2611	ASSAMAN	Durra
26	97ML0201	0.51	1729	NIORO TOUGOUNE	Durra
28	97ML0218	0.98	1879	BOULA	Durra
29	97ML0219	1.17	3470	BEIDIAT	Durra
31	97ML0223	1.08	3202	BEIDIAT	Durra
32	97ML0225-IS	0.48	1092	TOUROUGOUMBE	Durra
33	97ML0226-OR	0.88	2162	TOUROUGOUMBE	Durra
1	97ML0010	0.88	1403	WABARIA	Durra
36	97ML0279	1.01	2755	BEMA	Durra
37	97ML0281-IS	0.98	2984	BEMA	Durra
38	97ML0283	1	3307	BEMA	Durra
42	97ML0329	1.03	2445	MARENA	Durra
43	97ML0330	0.98	2766	MARENA	Durra
45	97ML0334	0.92	3646	MANDEHA	Durra
49	97ML0340	1.09	2014	KIRANE	Durra
50	97ML0342	0.91	3309	KIRANE	Durra
52	97ML0345	0.83	2443	KIRANE	Durra
56	97ML0446	0.48	1917	TIESSEMANA	Durra
14	97ML0162	0.82	3202	SEGUE	Durra
18	97ML0186	1.11	3382		Durra
59	97ML1611	1.09	3144	DABI	Durra
61	97ML1627	1.03	3213	GUIDIGATA	Durra
70	97ML1706	0.97	2089	FATAKARA	Durra
74	97ML1727	0.94	3486	ADER MALENE	Durra
76	97ML1733	0.95	2098	ZOUARA	Durra
77	97ML1736	1.12	3783	ZOUARA	Durra
78	97ML1748	0.7	1687	GUAINA	Durra
79	97ML1753	0.91	3487	MILALA	Durra
81	97ML1828	0.99	2113	BATAL	Durra
82	97ML1832	1.09	4189	WABARIA	Durra
83	97ML1838	0.94	2208	TACHARANE	Durra
84	97ML1840	0.26	839	TACHARANE	Durra
85	97ML1841	1.01	3255	TACHARANE	Durra
86	97ML1848	0.9	1629	GARGOUNA	Durra
60	97ML1615	1.09	4653	FARAMA	Durra-Bicolor
63	97ML1659	0.87	1867	KIRCHAMBA	Durra-Bicolor
64	97ML1661	0.68	1764	BANEYE	Durra-Bicolor
65	97ML1662	0.81	948	BANEYE	Durra-Bicolor
66	97ML1669	1.02	2563	KABAIKA	Durra-Bicolor
67	97ML1672	1.07	5219	KABAIKA	Durra-Bicolor
68	97ML1675	0.66	1713	ATTA	Durra-Bicolor
72	97ML1714	0.95	1918	M'BOUNA	Durra-Bicolor
75	97ML1729	0.92	2355	TIN AICHA	Durra-Bicolor
80	97ML1803	0.9	2497	SOUNDOUGOU	Durra-Bicolor
87	97ML1869	0.91	3223	DJEBOCK	Durra-Bicolor
2	97ML0014	0.72	1814	GROM GROM	Durra-Caudatum
12	97ML0159	0.97	1966	SEGUE	Guinea
7	97ML0150	1.07	2216	KONRONGA	Guinea
20	97ML0190-OR	0.88	2884	BALLE	Guinea
10	97ML0157	0.97	2848	NARA	Guinea
15	97ML0179	1.13	3366	DILLY	Guinea
22	97ML0194	0.9	3020	KORENA	Guinea
25	97ML0200	1.09	2400	NIORO TOUGOUNE	Guinea
30	97ML0221-IS	1.08	2265	BEIDIAT	Guinea

Number accession	Variety	Root length	Root density	Village/Origin	Race
34	97ML0227	0.73	1332	TOUROUGOUMBE	Guinea
35	97ML0277	1.13	4784	BEMA	Guinea
39	97ML0296	0.42	1358	YOURI	Guinea
40	97ML0297	0.55	2046	YOURI	Guinea
44	97ML0333	0.43	1734	MANDEHA	Guinea
46	97ML0336	0.94	2341	MANDEHA	Guinea
47	97ML0337-IS	1.26	3028	KIRANE	Guinea
51	97ML0343	0.85	1627	KIRANE	Guinea
53	97ML0347	1.06	1964	KIRANE	Guinea
54	97ML0351	1.05	2672	KOULOUM	Guinea
55	97ML0356	0.99	2115	DIAMOU	Guinea
6	97ML0106	1.18	2944	NIAMINA	Guinea
57	97ML1186	0.93	2656		Guinea
62	97ML1635	0.95	1788	SINGUO	Guinea
69	97ML1690	0.89	2572	MORI KOIRA	Guinea
71	97ML1709	0.56	1153	FATAKARA	Guinea
88	CSM 63E	0.95	2051	IER	Guinea_Improved
89	CSM 417E	0.89	1861	IER	Guinea_Improved
100	CSM 219	0.78	3351	IER	Guinea_Improved
21	97ML0193	0.88	1340	BALLE	Guinea-Bicolor
3	97ML0044	1.01	3848	KABAIKA	Guinea-Caudatum
27	97ML0203-IS	0.9	1308	NIORO TOUGOUNE	Guinea-Caudatum
58	97ML1514	0.31	845	GUINDIOGARE	Guinea-Caudatum
90	WASSA	0.87	2253	IER	Guinea-Caudatum_Improved
92	ZARRADJE	0.75	1851	IER	Guinea-Caudatum_Improved
97	97 SB F5DT 76-2	1.13	2271	IER	Guinea-Caudatum_Improved
98	DARRELL KEN	0.82	2608	IER	Guinea-Caudatum_Improved
99	97 SB F5DT 150	0.92	3254	IER	Guinea-Caudatum_Improved
94	97 SB F5DT 138	0.43	999	IER	Guinea-Caudatum_Improved
Mean		0.896	2219		
Significance		**	**		
LSD		0.2865	1302.1		
CV		19.8	36.4		
Mini		1.26	4784		
Max		0.26	300		

4. DISCUSSION

The study showed evidence of high variability among the varieties studied for root length and root density with a root length reaching over 1.00m. [15] indicated maize roots form a fascicule system that can reach deeper than one meter. These anchor roots can help the plant avoid lodging. Several studies on wheat indicated that the underground system can reach a considerable development in certain conditions. Theoretically, extensive root systems are the most favoured in environments where available moisture is found deep in the soil profile [16]. Wheat cultivars with extensive root system can operate a large volume of soil, absorb a large amount of water and have a considerable performance [17]. The absorption of water depends on the number of roots in a volume of soil, the size and the length of the roots, and several others factors. However, several authors pay particular attention to the depth of rooting [18,19]. The root fineness also plays a key role in the resistance to drought. It was positively related to drought resistance [20].

Table 4. Mean of root length and root density of different races

Race	Number accessions	Mean root length	Mean root density
Bicolor	1	1.0	2659
Caudatum	3	1.0	3094
Caudatum_Improved	4	0.7	1303
Caudatum-Bicolor	1	0.9	1981
Durra	42	0.9	2576
Durra-Bicolor	11	0.9	2611
Durra-Caudatum	1	0.7	1814
Guinea	24	0.9	2378
Guinea_Improved	3	0.9	2421
Guinea-Bicolor	1	0.9	1340
Guinea-Caudatum	3	0.7	2000
Guinea Caudatum_Improved	5	0.9	2447

Contrary to our thinking that sorghum varieties collected from 200 to 600 mm isohyets of rain would have a long and dense root system for adaptation to the poor and sandy soils of the Sahel, this study revealed short root system also adapted to these conditions. This study did not exhibit any root system pattern for the 4 races: Durra, Guinea, Caudatum and Bicolor and their 5 intermediates races: Durra bicolor, Caudatum Bicolor, Durra Caudatum, Guinea Caudatum and Guinea Bicolor. But it also clearly shows a correlation between root length and density indicating that an increase in the length of the root corresponds to an increased root density. The results of this study on the root system of local and improved sorghum cultivars grown in Mali can be useful in drought studies. Furthermore, the characteristics of the root system do play a role in drought resistance in cases where the roots are well developed before the occurrence of water deficit and are not affected by the lack of water.

5. CONCLUSION

The root system of a plant constantly provides the stems and leaves with water and dissolved minerals. The characterization of the root systems of sorghum can help to determine the capacity of the crop to access soil water and thus, can influence its adaptation to water-limited conditions. The method used in this study may be a useful tool for rapid phenotypic screening of root architecture. The diversity found in the root system could be considered a suitable target for large scale screening for root architecture in breeding populations and to evaluate the behaviour of the crop varieties of sorghum of different root systems in water stress conditions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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