Acta Scientific AGRICULTURE (ISSN: 2581-365X)

Volume 6 Issue 6 June 2022

Research Article

Root System Response of Selected *Rabi* Sorghum Genotypes to Varied Soil Moisture Regimes

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DOI: 10.31080/ASAG.2022.06.1144

Received: May 02, 2022

Published: May 27, 2022

Abstract

Drought is one of the abiotic stresses causing severe yield reduction in most *rabi* crops. Sorghum is called a camel crop for its tolerance to moisture stress conditions because of the morphophysiological mechanisms against water stress. One such mechanism is the developed and adaptable root system to moisture stress conditions. The root system serves as an interface between plant and soil and is of great significance as its role increases under moisture conditions. Despite all the mechanisms yield reduction under moisture stress is always there. To determine the amount of yield loss and the contribution of the root system modifications in withstanding the stress and yield reduction, a PVC column experiment was conducted in *rabi* 2019 consisting of five *rabi* sorghum genotypes (V_1: M 35-1, V_2: SPV2217, V_3: CSV 29R, V_4: CSH 15R and V_5: Basavanapada) under three moisture regimes (M_1: Well-watered conditions, M_2: Moisture stress between 40-60 DAS and M_3: Moisture stress between flowering and dough stage). Significant differences in root system responses were recorded among all the genotypes to the moisture stress at different stages of crop growth. When the moisture stress was imposed between 40 -60 DAS, SPV 2217 was more tolerant to drought at that stage of crop growth followed by M 35-1 with developed root system and modified root characteristics to the drought conditions like high RLD, R:S, SRL whereas Basavanapada was more susceptible to moisture stress at that stage which was the low yielding one among all the genotypes. Similarly when the moisture stress was imposed between the flowering and dough stage (M_3) the performance of the root system of M 35-1 was better compared to other genotypes and CSV 29R was very susceptible to the post-flowering moisture stress. In the *rabi* sorghum growing areas with pre- flowering moisture stress, SPV 2217 and in the post-flowering moisture stress M 35-1 will be considered as drought tolerant and high yielding genotypes compared to other genotypes.

Keywords: *Rabi* Sorghum; Genotypes; Moisture Stress; Crop Growth Stages; Root Traits Modification; Drought Tolerance; Yield Response

Abbreviations

RSA: Root System Architecture; RV: Root Volume; RS: Root to Shoot Ratio**;** RLD: Root Length Density; SRL: Specific Root Length

Introduction

Plant root system architecture (RSA) is of great agronomic significance because it is an essential determinant for plant anchoring and mechanical support, proliferation, storage, water and nutrient uptake, and serves as the main interface between the plant and various biotic or abiotic factors [1]. In recent years, plant root system architecture has thus emerged as the core focus for plant biology study. The sorghum root system consists of three root types: primary roots, secondary or adventitious roots, and roots of bracelets or buttresses. Primary roots emerge from the radicle and then die.

The secondary or adventitious roots grow from the mesocotyledon, first node and the second internode and above. These roots are laterally branched and ultimately provide the plant with nutrients. Brace or buttress roots grow above the ground level from the root primordia of the basal nodes [2]. Plants root growth, root density, it's proliferation, and size is major responses of plants to moisture limited conditions [3]. Optimizing the root system can lead to a significant yield advantage in water-limited environments. The root system is the important part of the plant which controls many aspects of shoot growth and development and is involved in the acquisition of water, nutrients, anchorage and production of plant hormones, organic acids: etc. [4]. Root morphology and physiology are related closely to the growth and development of above- ground parts [5,6]. The root system modifies according to water availability. RSA modification role comes into play when water resources are limited. Coarse, downward-growing nodal roots might be critical for better penetration through hardpans, but a large percentage of the total root length is composed of fine roots, which are more important for water and nutrient uptake under all conditions [7]. Root length is an important root trait for crop productivity under stress as it determines the size of contact of the root system with soil and facilitates plant acquisition of below- ground resources (water and nutrients) from the soil.

Drought is one of the most serious abiotic stresses responsible for causing severe morphological, biochemical and physiological damage resulting in low crop yields. Normal physiological processes such as transpiration, stomatal conductance and photosynthesis are adversely affected by drought. Recovery of these processes following rewatering depends on the intensity, frequency and duration of drought stress [8]. It is a serious production constraint for world agriculture limiting crop productivity and quality and has long-term consequences on regional and global food security. Drought restricts root and shoots growth through declining physiological processes [9]. Drought reduces root dry matter production and rooting depth resulting in lower water and nutrient uptake from subsoils. The plant forms the first line of defense against drought stress through its roots. Adaptation of the root system to fluctuating water stress may be more complicated than progressive drought stress or constant waterlogging conditions [10]. More root thickness, high root length density and a deep rooting system are important root traits to cope with drought stress under changing environmental conditions [11]. In India, sorghum is cultivated in the *rabi* season under stored soil moisture which experiences drought at different stages of crop growth. Hence, under dryland conditions, water stress is a major constraint limiting sorghum crop growth and reducing its productivity. Despite sorghum being one of the most drought-tolerant crops called as the 'crop camel' is prone to yield loss under moisture stress situations and the level of loss depends on the stage of the crop at which stress occurred, intensity and duration of the stress. There is a great adaptability and the crop has wide genetic diversity such that the genotypes differ in their mechanisms to escape, avoid and tolerate drought conditions. Hence understanding the genetic basis for drought tolerance mechanisms is of fundamental importance in the development of cultivars that could be better adapted to dry land conditions. Selection of suitable genotypes to particluar location so that they can adapt to the moisture stress at a particular stage of crop growth and yield high and increase productivity of the crop. The experiment was carried out with objectives as follows

- To study the root trait modifications in response to moisture stress at different crop growth stages
- To assess the yield response to moisture stress at different stages of crop growth

Materials and Methods

Experimental conditions

The experiment was conducted using PVC columns (1 m height and 15 cm diameter) during *rabi* 2019 in field conditions at AICRP on sorghum, MARS, UAS Dharwad (15^0 29' N latitude, $74^0$59' E longitudes at an altitude of 689m above mean sea level). Five *rabi* sorghum genotypes *viz.,* M 35-1, SPV2217, CSV 29R, CSH 15R and Basavanapada were used in this experiment. Seeds were sown in the PVC columns in which soil was bought to field capacity after saturation. Each pot contained 18 kg of red loam soil with a pH of 7.25. Five seeds were sown in each PVC column and only a single seedling was retained by thinning out the remaining seedlings after germination. The experiment was laid out in a completely randomized design replicated thrice with factorial combinations of five genotypes (M 35-1, SPV 2217, CSV 29R, CSH 15R and Basavanapada), three moisture regimes (well- watered regime [M_1], moisture stress at 40-60 DAS [M_2] and moisture regime with water stress between flowering and dough stage [M_3]). Each pot was fertilized with 50:25:0 kg ha^{-1} of NPK. Nitrogen was applied in two split doses *i.e.*, 50 percent as basal and 50 percent at 30 days after sowing. Soil water potential was monitored using the theta probe. Moisture stress was induced at the critical stages of the crop growth. After the completion of the stress period the sample columns are used for root collection. The soil in the column is divided into 20 cm lengths and the soil of the total column is washed and roots are collected for the root trait study.

Data collection

Roots are washed with distilled water, washed roots of sorghum from various treatments were scanned and root parameters were measured with a Win RHIZO scanner (Regents Instruments, Quebec, Canada) at the end of each moisture stress i.e., between 40-60 DAS and between flowering and dough stages.

Root volume (RV)

Roots are washed with distilled water, washed roots of sorghum from various treatments were scanned and root volume (mm^3) was measured under a WinRHIZO scanner (Regents Instruments, Quebec, Canada) after the end of mentioned stress periods.

Length per unit volume (Root length density)

RLD ($km\ cm^{-3}$) is calculated by dividing the root length per unit volume of soil [11].

$$\text{RLD } (km\ cm^{-3}) = \frac{Root\ length}{Unit\ soil\ volume}$$

Root to shoot ratio (R:S)

R:S ratio was calculated by dividing the RDM by the above ground shoot dry matter yield. The ratio of root dry weight (g) to shoot dry weight (g) was calculated.

$$\text{R:S ratio} = \frac{Root\ dry\ weight}{Shoot\ sry\ weight}$$

Specific root length (SRL)

SRL is calculated by dividing the root length by root dry weight ($cm\ g^{-1}$) [12].

$$\frac{Rootlength}{Rootdryweight}$$

Statistical analysis

The data collected from the experiment at different growth stages will be subjected to statistical analysis as described by [13]. The level of significance used in the 'F' and the t-test' will be P= 0.01. Critical difference (CD) values were calculated wherever the 'F' test will be found significant.

Figure 1: Root scanner (WinRHIZO).

Figure 2: PVC columns of the experiment.

Results and Discussion

Root volume (RV)

Among all the genotypes in the moisture -stressed regimes decrease in the root volume was recorded. Higher root volume was recorded in the well-watered moisture regime in the surface layers of the column in all genotypes which might be due to surplus availability of water on surface layers for more moisture absorption and reduced root volume was recorded with an increase in depth at deeper layers. Root volume decrease was less in the deeper layers of the column compared to the surface layers of the column. The per cent decrease in the root volume in the moisture-stressed conditions varied among the genotypes. The drought -tolerant genotypes recorded a less per cent decrease compared to the drought susceptible genotypes. The high yielding genotype SPV 2217 has recorded higher root volume in deeper layers when compared to other genotypes and lower root volume was recorded by Basavanapada which was the low yielder under the moisture stress condition. These results are in agreement with the findings of [14] who reported a positive correlation between root volume and yield in drought conditions. In the present study also root volume recorded a considerable positive correlation with grain yield (r = 0.74).

After first moisture stress between 40-60 DAS there was a significant difference between genotypes, moisture regimes and their interaction effects (Table 1). At all the depths CSH 15R (V_4) followed by CSV 29R (V_3) has recorded higher root volume among all the genotypes in well-watered moisture regime. After the first moisture stress, SPV 2217 (V_2M_2) recorded a 46 percent decrease in root volume in the surface layers (20 cm) and a negligible decrease of root volume (2.9% and 5.3%) at deeper layers *i.e*, at 80 cm and 100 cm depth of the column. Basavanapada in the moisture regime with water stress between 40-60 DAS (V_5M_2) has recorded a higher per cent of decrease 57.74 percent and 45 percent at surface layers 20 cm and 60 cm depth and even in the deeper layers of 100 cm depth 33 percent decrease in the root volume was recorded. Lack of soil moisture which reduced the size and growth of roots and hence root volume.

Treatments (Varieties)	**Root volume (mm^3) after first moisture stress between 40-60 DAS**				
	0-20 cm	**20-40 cm**	**40-60 cm**	**60-80 cm**	**80-100 cm**
Factor –I					
V_1- M 35-1	8.66	3.36	3.06	3.04	1.78
V_2- SPV 2217	8.89	4.16	3.38	3.33	2.34
V_3- CSV 29R	9.37	4.04	3.89	2.42	1.60
V_4- CSH 15R	10.93	4.19	2.44	4.61	4.03
V_5- Basavanapada	7.03	2.94	3.28	2.16	1.12
S. Em. ±	0.10	0.04	0.05	0.06	0.03
C.D. (P = 0.01)	0.40	0.14	0.20	0.22	0.10
Factor –II (Moisture regimes)					
M_1- Well watered moisture regime	10.74	4.10	3.58	3.69	2.68
M_2- Moisture stress between 40-60 DAS	5.38	2.96	2.42	1.99	1.18
M_3- Moisture stress between flowering and dough stage	10.81	4.16	3.62	3.65	2.67
S. Em. ±	0.08	0.03	0.04	0.04	0.02
C.D. (P = 0.01)	0.31	0.11	0.15	0.17	0.08
Interaction (V×M)					
V_1M_1	9.49	3.70	3.26	3.60	2.28
V_1M_2	6.92	2.62	2.63	1.98	0.76
V_1M_3	9.57	3.75	3.30	3.54	2.31
V_2M_1	10.54	4.19	3.25	3.40	2.43
V_2M_2	5.69	4.09	3.60	3.33	2.30
V_2M_3	10.44	4.21	3.29	3.25	2.29
V_3M_1	11.22	4.34	4.73	3.04	1.98
V_3M_2	5.58	3.32	2.15	1.09	0.95
V_3M_3	11.31	4.45	4.80	3.12	1.88
V_4M_1	13.74	5.03	2.82	6.20	5.40
V_4M_2	5.02	2.48	1.64	1.67	1.05
V_4M_3	14.04	5.06	2.84	5.97	5.64
V_5M_1	8.71	3.23	3.85	2.22	1.29
V_5M_2	3.68	2.29	2.09	1.90	0.86
V_5M_3	8.69	3.31	3.89	2.35	1.21
S. Em. ±	0.18	0.06	0.09	0.10	0.05
C.D. (P = 0.01)	0.69	0.25	0.35	0.37	0.18

Table 1: Root volume of *rabi* sorghum at 60 DAS (after first moisture stress between 40-60 DAS) at different depths of soil column as determined by different genotypes, moisture regimes and their interaction.

After the second moisture stress between flowering and dough stage increase in the root volume with an increase in age of the crop was recorded (Table 2). At all depths, CSV 29R (V_3) in the surface layers and SPV 2217 (V_2) in the deeper layers have recorded higher root volumes among all the genotypes. After the second moisture stress between flowering and dough stage, M 35-1 (V_1M_3) has recorded a 44.87, 27.35 percent decrease in root volume in the surface layers (20 cm, 40 cm depth of column) and a negligible decrease of root volume at deeper layers i.e., at 80 cm and 100 cm depth of the column. CSV 29R (V_3M_3) has recorded a higher percent of decrease (72.03%) at surface layers of 20 cm and even in the deeper layers of 100 cm depth 16.5 per cent decrease in the root volume was recorded.

Treatments	Root volume (mm^3) after second moisture stress between flowering and dough stage				
	0-20 cm	20-40 cm	40-60 cm	60-80 cm	80-100 cm
Factor –I (Varieties)					
V_1- M 35-1	17.21	9.66	7.42	5.53	3.76
V_2- SPV 2217	14.67	9.04	8.19	6.33	4.47
V_3- CSV 29R	25.53	8.30	7.23	6.12	3.06
V_4- CSH 15R	18.46	5.67	4.24	4.88	2.77
V_5- Basavanapada	17.46	7.87	5.09	3.14	1.74
S. Em. ±	0.25	0.08	0.07	0.06	0.04
C.D. (P = 0.01)	0.98	0.33	0.29	0.25	0.14
Factor –II (Moisture regimes)					
M_1- Well watered moisture regime	24.02	9.10	7.34	5.62	3.11
M_2- Moisture stress between 40-60 DAS	20.26	7.65	5.75	5.31	2.84
M_3- Moisture stress between flowering and dough stage	11.72	7.58	6.21	4.67	3.53
S. Em. ±	0.20	0.06	0.06	0.05	0.03
C.D. (P = 0.01)	0.76	0.25	0.23	0.19	0.11
Interaction (V×M)					
V_1M_1	21.55	11.37	6.72	7.04	4.52
V_1M_2	18.19	9.35	7.61	4.49	1.24
V_1M_3	11.88	8.26	7.94	5.07	5.54
V_2M_1	19.08	9.93	11.45	6.34	3.17
V_2M_2	14.40	8.03	6.44	7.25	5.57
V_2M_3	10.53	9.16	6.68	5.40	4.67
V_3M_1	35.01	9.17	8.62	7.18	3.59
V_3M_2	31.80	8.59	7.41	7.16	3.58
V_3M_3	9.79	7.15	5.64	4.01	2.01
V_4M_1	22.75	7.12	5.46	4.24	2.12
V_4M_2	17.91	4.65	3.32	5.53	2.76
V_4M_3	14.73	5.23	3.95	4.87	3.43
V_5M_1	21.72	7.91	4.47	3.31	2.15
V_5M_2	19.00	7.63	3.96	2.12	1.06
V_5M_3	11.66	8.07	6.83	4.00	2.00
S. Em. ±	0.44	0.14	0.13	0.11	0.06
C.D. (P = 0.01)	1.70	0.56	0.50	0.43	0.25

Table 2: Root volume of *rabi* sorghum after second moisture stress between flowering and dough stage at different depths as effected by different genotypes, moisture regimes and their interaction.

Root to shoot ratio (R:S)

Under moisture stress conditions increase in R:S compared to the well-watered conditions was recorded. Significant difference among the genotypes, moisture regimes and their interaction has been recorded (Table 3). The increase in R:S in stress conditions might be due to preferential assimilation distribution to roots, increased root length and root hairs in deeper layers which have grown in search of moisture. High-yielding genotypes recorded higher R:S ratio under moisture stress conditions and the opposite in low-yielding genotypes. Similar findings were reported by [15,16] that there was a positive correlation of root to shoot ratio with grain yield under moisture limited conditions.

Treatments	Root to shoot ratio	
	After the first moisture stress between 40-60 DAS	After the second moisture stress between flowering and dough stage
Factor –I (Varieties)		
V_1- M 35-1	0.32	0.15
V_2- SPV 2217	0.38	0.15
V_3- CSV 29R	0.34	0.16
V_4- CSH 15R	0.27	0.13
V_5- Basavanapada	0.25	0.15
S. Em. ±	0.003	0.002
C.D. (P = 0.01)	0.011	0.006
Factor –II (Moisture regimes)		
M_1- Well watered moisture regime	0.268	0.135
M_2- Moisture stress between 40-60 DAS	0.402	0.127
M_3- Moisture stress between flowering and dough stage	0.265	0.176
S. Em. ±	0.002	0.001
C.D. (P = 0.01)	0.008	0.005
Interaction (V×M)		
V_1M_1	0.271	0.135
V_1M_2	0.413	0.128
V_1M_3	0.267	0.194
V_2M_1	0.298	0.129
V_2M_2	0.540	0.126
V_2M_3	0.290	0.182
V_3M_1	0.317	0.158
V_3M_2	0.403	0.149

V_3M_3	0.312	0.178
V_4M_1	0.239	0.115
V_4M_2	0.326	0.114
V_4M_3	0.239	0.148
V_5M_1	0.216	0.139
V_5M_2	0.327	0.119
V_5M_3	0.216	0.179
S. Em. ±	0.005	0.003
C.D. (P = 0.01)	0.018	0.011

Table 3: Root to Shoot ratio of *rabi* sorghum at 60 DAS (after first moisture stress between 40-60 DAS) and after second moisture stress between flowering and dough stage as influenced by different genotypes, moisture regimes and their interaction.

After the first moisture stress between 40-60 DAS, SPV 2217 (V_2M_2) has recorded higher percent increase (86%) and the lowest percent increase (49.3%) was recorded by Basavanapada (V_5M_2) compared to the respective genotypes in the well-watered moisture regimes. After second moisture stress between flowering and dough stage M 35-1 (V_1M_3) has recorded higher per cent increase (44%) and the lowest per cent increase (12.6%) was recorded by the genotype CSV 29R (V_3M_3) compared to the respective genotypes in the well-watered moisture regimes. A higher value was recorded after moisture stress between 40-60 DAS and very little increase in stress between flowering and dough stage. This might be due to the reason that after flowering, plant diverts most of the carbon resources to shoot and hence to panicle than to roots. These results were supported by [17] who reported that no increase in root-to-shoot ratio by stress at the flowering stage.

Root length density (RLD)

In the present study, Root length per unit volume (Root length density) in well-watered conditions decreased with an increase in depth. In moisture stress condition root length density increased with increase in depth. [18,19] who documented that under water stress root length density was more and uniformly distributed. Under moisture stress conditions, RLD increased in all genotypes (Table 4,5). But the per cent increase was higher in the drought-tolerant genotypes compared to less tolerant ones [20]. reported higher root length density was noticed in water deficit conditions compared to watered conditions and root length density was less affected under moisture stress conditions in drought-tolerant and high yielding genotype which was reported by [21]. Length of root increased in deeper layers in search of moisture and increase was higher in high yielding genotypes which might have contributed to increased uptake of moisture under stress condition that might be a reason for increased yield. The percent increase in RLD increased with increase in depth of the soil column in the tolerant genotypes whereas the increase in the deeper layers was less or none in the susceptible genotypes (Table 6,7).

Treatments	Root length (km cm^{-3}) density after first moisture stress between 40-60 DAS				
	0-20 cm	20-40 cm	40-60 cm	60-80 cm	80-100 cm
Factor –I (Varieties)					
V_1- M 35-1	4.28	4.41	4.32	4.30	3.05
V_2- SPV 2217	4.30	5.14	4.30	3.67	2.84
V_3- CSV 29R	5.33	4.86	3.69	2.14	1.74
V_4- CSH 15R	4.81	4.56	2.55	1.90	1.47
V_5- Basavanapada	4.57	4.96	4.66	3.53	3.01
S. Em. ±	0.04	0.04	0.03	0.03	0.03
C.D. (P = 0.01)	0.16	0.16	0.18	0.11	0.13
Factor –II (Moisture regimes)					
M_1- Well watered moisture regime	5.55	4.98	3.44	2.77	2.29
M_2- Moisture stress between 40-60 DAS	2.97	4.56	4.94	3.71	2.68
M_3- Moisture stress between flowering and dough stage	5.45	4.82	3.33	2.84	2.29
S. Em. ±	0.03	0.03	0.03	0.02	0.03
C.D. (P = 0.01)	0.12	0.12	0.10	0.09	0.10
Interaction (V×M)					
V_1M_1	5.31	4.53	3.97	3.36	2.60
V_1M_2	2.41	3.86	5.21	6.08	4.28
V_1M_3	5.11	4.83	3.77	3.45	2.27
V_2M_1	5.60	5.35	3.47	2.44	1.64
V_2M_2	1.80	4.91	6.16	6.43	4.96
V_2M_3	5.50	5.15	3.27	2.14	1.93
V_3M_1	6.03	4.46	2.94	1.91	1.71
V_3M_2	3.92	6.66	5.19	2.61	1.81
V_3M_3	6.03	3.46	2.94	1.91	1.69

V_4M_1	5.58	5.10	1.97	1.72	1.58
V_4M_2	3.27	3.49	3.95	1.90	1.40
V_4M_3	5.58	5.10	1.72	1.97	1.44
V_5M_1	5.24	5.46	4.84	4.31	3.94
V_5M_2	3.44	3.86	4.19	1.46	0.96
V_5M_3	5.04	5.56	4.94	4.61	4.14
S. Em. ±	0.07	0.07	0.06	0.05	0.06
C.D. (P = 0.01)	0.27	0.27	0.23	0.20	0.23

Table 4: Root length density (RLD) of *rabi* sorghum at 60 DAS (after first moisture stress between 40-60 DAS) at different soil column depths as effected by different genotypes, moisture regimes and their interaction.

Treatments	**Root length (km cm^{-3}) density after second moisture stress between flowering and dough stage**				
	0-20 cm	**20-40 cm**	**40-60 cm**	**60-80 cm**	**80-100 cm**
Factor –I (Varieties)					
V_1- M 35-1	4.66	6.47	6.20	2.90	1.38
V_2- SPV 2217	4.67	5.96	5.40	3.67	1.00
V_3- CSV 29R	4.15	6.11	4.92	2.71	1.02
V_4- CSH 15R	4.33	4.68	4.66	1.70	0.82
V_5- Basavanapada	4.10	6.04	6.01	2.66	1.11
S. Em. ±	0.038	0.067	0.062	0.028	0.009
C.D. (P = 0.01)	0.148	0.261	0.241	0.110	0.0037
Factor –II (Moisture regimes)					
M_1- Well watered moisture regime	5.50	6.01	5.50	2.61	1.08
M_2- Moisture stress between 40-60 DAS	4.32	5.46	4.49	2.34	0.86
M_3- Moisture stress between flowering and dough stage	3.32	6.09	6.32	3.25	1.26
S. Em. ±	0.030	0.052	0.048	0.022	0.007
C.D. (P = 0.01)	0.115	0.202	0.187	0.085	0.028
Interaction (V×M)					
V_1M_1	5.22	6.61	6.57	2.00	1.00
V_1M_2	4.04	6.93	5.43	2.37	1.18
V_1M_3	4.73	5.88	6.60	4.34	1.97
V_2M_1	6.33	6.32	5.19	3.06	1.53
V_2M_2	4.01	6.19	4.99	3.66	0.83
V_2M_3	3.66	5.36	6.02	4.30	0.65
V_3M_1	6.34	6.03	4.09	3.14	1.07
V_3M_2	3.99	5.31	5.49	2.38	0.69
V_3M_3	2.13	6.99	5.18	2.61	1.31
V_4M_1	5.72	4.46	4.44	1.82	0.87
V_4M_2	4.44	3.71	2.70	1.34	0.64
V_4M_3	2.82	5.87	6.84	1.96	0.94
V_5M_1	3.88	6.62	7.23	3.02	0.95
V_5M_2	5.14	5.14	3.84	1.95	0.94
V_5M_3	3.28	6.37	6.96	3.02	1.45
S. Em. ±	0.066	0.12	0.107	0.049	0.016
C.D. (P = 0.01)	0.257	0.45	0.417	0.190	0.064

Table 5: Root length density (RLD) of *rabi* sorghum after second moisture stress between the flowering and the dough stage at different soil column depths as determined by genotypes, moisture regimes and their interaction.

Treatments	**Specific root length (cm g^{-1}) after first moisture stress between 40-60 DAS**				
	0-20 cm	**20-40 cm**	**40-60 cm**	**60-80 cm**	**80-100 cm**
Factor –I (Varieties)					
V_1- M 35-1	878.87	3404.31	4337.93	4595.50	4393.61
V_2- SPV 2217	861.09	4125.99	3706.95	2985.72	4540.23
V_3- CSV 29R	918.11	2834.38	3296.04	3805.91	3950.08
V_4- CSH 15R	529.62	2113.00	4039.54	4341.19	3295.47
V_5- Basavanapada	1177.57	4510.38	3302.37	2804.86	2959.06
S. Em. ±	9.11	39.98	35.93	46.30	32.91
C.D. (P = 0.01)	35.41	155.50	139.75	180.06	128.00
Factor –II (Moisture regimes)					
M_1- Well watered moisture regime	771.11	3552.23	3529.72	3315.49	3593.23
M_2- Moisture stress between 40-60 DAS	1065.34	3014.38	4168.26	4426.93	4300.61
M_3- Moisture stress between flowering and dough stage	782.71	3626.23	3511.72	3377.49	3589.23
S. Em. ±	7.05	30.97	27.84	35.86	25.49

C.D. (P = 0.01)	27.43	120.45	108.25	139.47	99.15
Interaction (V×M)					
V_1M_1	890.84	3141.82	3987.62	4114.57	3980.13
V_1M_2	904.93	3529.30	4938.55	5357.35	5120.56
V_1M_3	840.83	3541.82	4087.62	4314.57	4080.13
V_2M_1	1007.44	4549.36	3668.18	2258.42	3816.35
V_2M_2	468.41	3379.25	4084.49	4640.32	6187.98
V_2M_3	1107.43	4449.36	3368.18	2058.42	3616.35
V_3M_1	632.80	2769.10	2928.89	3483.59	3983.59
V_3M_2	1438.73	2924.95	3990.33	4350.56	4103.06
V_3M_3	682.80	2809.10	2968.89	3583.59	3763.59
V_4M_1	202.19	1973.27	3936.55	4016.52	3235.32
V_4M_2	1186.49	2472.46	4285.51	4880.54	3215.76
V_4M_3	200.19	1893.26	3896.55	4126.52	3435.32
V_5M_1	1122.29	5327.61	3127.35	2704.35	2950.75
V_5M_2	1328.13	2765.94	3542.41	2905.88	2875.67
V_5M_3	1082.29	5437.60	3237.35	2804.35	3050.75
S. Em. ±	15.77	69.25	62.24	80.19	57.01
C.D. (P = 0.01)	61.34	269.34	242.06	311.87	221.70

Table 6: Specific root length (SRL) of *rabi* sorghum at 60 DAS (after the first moisture stress between 40-60 DAS) at different depths of soil column effected by different genotypes, moisture regimes and their interaction.

Treatments	**Specific root length (cm g^-1^)after second moisture stress between flowering and dough stage**				
	0-20 cm	**20-40 cm**	**40-60 cm**	**60-80 cm**	**80-100 cm**
Factor –I (Varieties)					
V_1- M 35-1	426.16	2684.03	3118.09	1289.93	711.63
V_2- SPV 2217	460.30	1343.63	2489.70	1227.50	563.75
V_3- CSV 29R	159.43	1706.51	1888.74	1343.95	671.98
V_4- CSH 15R	449.75	1721.93	2562.60	1225.55	579.44
V_5- Basavanapada	495.37	1777.35	2486.57	1766.37	949.85
S. Em. ±	5.07	17.99	24.81	15.80	6.21
C.D. (P = 0.01)	19.73	69.97	96.50	61.44	24.14
Factor –II (Moisture regimes)					
M_1- Well watered moisture regime	394.02	1713.24	2114.32	1128.46	584.23
M_2- Moisture stress between 40-60 DAS	325.44	1999.54	2698.45	1362.72	711.36
M_3- Moisture stress between flowering and dough stage	475.14	1827.30	2714.65	1620.80	790.40
S. Em. ±	3.93	13.94	19.22	12.24	4.81
C.D. (P = 0.01)	15.29	54.20	74.75	47.59	18.70
Interaction (V×M)					
V_1M_1	401.35	2361.42	2314.73	1253.35	726.67
V_1M_2	518.49	3045.18	3477.45	1040.73	520.37
V_1M_3	358.64	2645.49	3562.09	1575.72	887.86
V_2M_1	701.27	1331.86	1821.05	1150.65	575.33
V_2M_2	408.75	1274.33	2412.25	1152.15	426.08
V_2M_3	270.87	1424.70	3235.79	1379.69	689.85
V_3M_1	68.39	1438.67	2062.59	1210.74	605.37
V_3M_2	139.02	2041.38	1876.18	1212.37	606.19
V_3M_3	274.92	1639.49	1727.46	1608.74	804.37
V_4M_1	219.98	1371.33	1949.95	1192.07	596.03
V_4M_2	854.34	1879.64	2783.98	1128.19	564.10
V_4M_3	321.67	1914.82	2953.87	1356.39	578.19
V_5M_1	411.59	2062.90	2423.29	835.51	417.75
V_5M_2	752.84	1757.18	2942.39	2280.16	1440.08
V_5M_3	336.81	1511.98	2094.02	2183.44	991.72
S. Em. ±	8.79	31.16	42.98	27.36	10.75
C.D. (P = 0.01)	34.18	121.20	167.14	106.41	41.82

Table 7: Specific root length (SRL) of *rabi* sorghum after the second moisture stress between flowering
and dough stage at different depths of soil column as effected by different genotypes, moisture regimes
and their interaction.

After first moisture stress between 40-60 DAS SPV 2217 (V_2M_2) has recorded a higher per cent increase (43.66%, 62.1% and 67%) in RLD at deeper layers i.e., 60, 80 and 100 cm of the soil column respectively. Whereas Basavanapada in the stressed moisture regime (V_5M_2) has recorded very negligible or no increase in the RLD in the deeper layers of the soil column. Similar findings were reported by [22] that the genotype having higher root length density at deeper depths showed more rapid soil moisture capture and higher shoot biomass. After the second moisture stress between flowering and dough stage, M 35-1 in the moisture stressed regime (V_1M_3) has recorded an increase in the RLD (14%, 54%, 49.2%) in the deeper layers (at 60, 80 and 100 cm depth of soil column) compared to the well-watered regimes and the percent increase in the RLD was higher in the deeper layers of the soil column. Compared to the drought-tolerant genotypes CSV 29R (V_3M_3) which was very susceptible to post -flowering moisture stress has recorded a lesser per cent increase (13.7%, 21%) in surface layers at 40 and 60 cm and a very negligible increase (6%) in the deeper layers at 80-100 cm.

Specific root length (SRL)

SRL in moisture stress conditions increased with an increase in depth compared to well-watered conditions. In the moisture stress conditions drought tolerant genotypes have recorded a higher percent increase in SRL in the deeper layers compared to the surface layers whereas the drought susceptible genotypes have recorded a negligible increase in the SRL. Increase in specific root length at deeper depths helped to extract more moisture which might have helped to increase yield in high yielding genotypes [23]. reported that in maize genotype has a higher specific root length confirming its drought tolerance and higher yield.

After the first moisture stress between 40-60 DAS, SPV 2217 (V_2M_2) has recorded increase in the SRL (10.9%, 19.25%, 23.2%, 22.2% at 40, 60, 80 and 100 cm depth of the soil column). Whereas Basavanapada (V_5M_2) has recorded no increase of SRL in the surface layers and a very negligible (7%) increase in the deeper layers of the soil column. After the second moisture stress between flowering and dough stage M 35-1 in the moisture stressed regime (V_2M_3) has recorded higher per cent increase in the SRL (53.9%, 26%) in the deeper layers of soil column (60, 80 cm). Whereas CSV 29R (V_3M_3) has recorded the lowest or negligible increase in the SRL compared to all other genotypes in the moisture-stressed conditions. Beacause of more root dry weight per unit root length in the surface zone and root dry weight in deeper layers is lesser than in surface layers of soil because of increased root fineness and increased SRL [18].

Yield of the genotypes

Significant differences were recorded among the genotypes and moisture regime interactions concerning yield (Figure 3). Higher grain yield was recorded by the CSV 29R in the well-watered moisture regime [V_3M_1 (3.43 t ha^{-1})] followed by M 35-1 and SPV 2217 in the well-watered moisture regime [V_1M_1 (3.23 t ha^{-1}) and V_2M_1 (3.33 t ha^{-1})] which were on par with the highest treatment. Whereas Basavanapada in the moisture regime with water stress between 40-60 DAS [V_5M_2 (1.58 t ha^{-1})] has registered the lower grain yield among all the treatments.

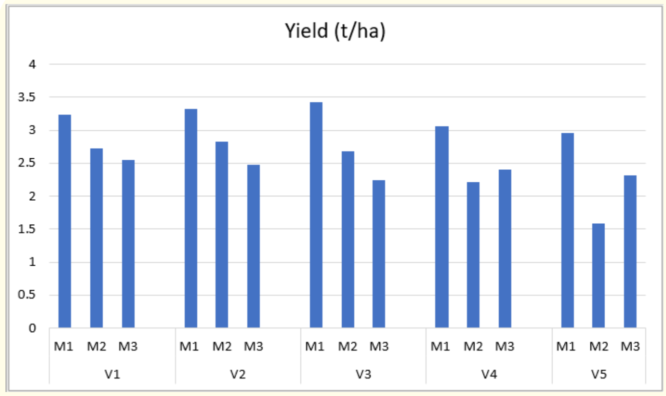

Figure 3: Yield and yield parameters of rabi sorghum as influenced by different genotypes, moisture regimes and their interaction.

Conclusion

The root system development of five *rabi* sorghum genotypes was affected by different moisture regimes. The five genotypes differed in their response to soil moisture stress. In the first moisture stress i.e., between 40-60 DAS, SPV 2217 (V_2) was more tolerant to moisture stress, while Basavanapada (V_5) showed an inconsistent response to water deficit conditions and was recorded as sensitive to pre-flowering moisture stress. When the moisture stress was applied between the flowering and dough stage, M 35-1 (V_1) was recorded as the tolerant genotype to post-flowering moisture stress, whereas CSV 29R (V_3) was recorded as the most susceptible one to moisture stress between flowering and dough stage. In the present study, SPV 2217 and M 35-1 were recorded to be tolerant to drought and high yielders at pre and post-flowering moisture stress respectively compared to other genotypes.

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