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Leaf Conductance Study on Twelve (12) Genotypes of Sorghum [*Sorghum bicolor* (L.) Moench]

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Authors' contributions

This work was carried out in collaboration among all authors. Author CFT conducted the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AT and AD managed the analyses of the study, managed the literature searches and translated the manuscript in English. Author VV reviewed the draft and mentored team. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Enhancing transpiration efficiency (TE), defined as biomass accumulation per unit water transpired, may be an effective approach to increasing sorghum yield in arid and semi-arid regions under drought conditions. Water use efficiency was compared among 12 sorghum cultivars collected from the ICRISAT Genebank and representing diverse origins. Plants were cultivated in a split plot experimental design using pots with two factors in 5 replications. An irrigation system with two levels: the "well water", and "water stress" were applied. Plastic bags were used to wrap the pots after the phase of water saturation. Transpiration Efficiency (TE) was used to evaluate the performance of a genotype in water deficit conditions. The parameters such as leaf weight, stem weight and root weight were measured and the data were analyzed using the statistical software tool GenStat version 19. Leaf weight, stem weight and root weight varied significantly between genotypes under well water conditions while under water stress conditions only the stem weight

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measured was significantly different among the genotypes. Significant differences between genotypes for leaf canopy conductance were found. The leaf canopy conductance was weakly correlated to the stem weight and root weight in both well-watered and water stress conditions.

Keywords: Sorghum; transpiration efficiency; leaf canopy conductance; water stress.

1. INTRODUCTION

In the Sahel, crop productivity is particularly affected by the onset and ending date of the rainy season, and by the distribution and intensity of rainfall events [1,2]. Climate change is expected to increase vulnerability in all agro-ecological zones of Mali and other country of the region through rising temperature and more erratic rainfall, which will have drastic consequences on food security and economic growth [3,4].

A survey on drought probability and the effects of drought has recently been undertaken in all tropical farming systems of the world and the result showed that the millet/sorghum system in the Sahel is one of the most drought prone areas in the world and stunting of children as a result of inadequate nutrition is widespread [5]. Targeting these areas for development assistance can therefore increase the Sahelian countries' adaptation to drought and reduce poverty. Water being the main limiting factor, enhancing transpiration efficiency (TE), defined as biomass accumulation per unit water transpired, may be an effective approach to increasing sorghum yield in arid and semi-arid regions under drought conditions. The main objective of this work was to compare leaf conductance among various sorghum genotypes.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was conducted at the International Crops Research Institute for the Semi-arid Tropics (ICRISAT-Patancheru campus). The site is a sub basin with two main watersheds. One comprises the northern quarter of the farm (complete and self-contained) and the other, in the south, is part of a much larger watershed. The average annual rainfall for the area is 800 mm. The experimental farm is representative of the dryland environment – consisting of two major soil groups found in the semi- arid tropics, the red alfisols and the black vertisols– that allows testing of breeding lines and crop production systems in two different environments within one location. The arable areas in the two soil types are subdivided into irrigated and non-irrigated, sprayed and non-sprayed, and low and high fertility areas to represent low and high input environments.

2.2 Plant Materials

The study looked at 12 sorghum cultivars collected from ICRISAT Genebank representing divers' origins. Table 1 gives the list of the sorghum genotypes used for the study.

2.3 Methodology

Leaf conductance or stomatal conductance is a measure of the degree of stomatal opening and can be used as an indicator of plant water status. Many studies have demonstrated the stomatal response in plants to leaf water status and the environment. These studies reveal that stomata respond in ways consistent with their role in controlling transpiration and maintaining leaf water status [6]. Leaf conductance is small, and decreases as the water potential falls and the vapor pressure deficit increases.

The 12 sorghum genotypes were cultivated in a split plot experimental design using pots with two factors in 5 replications. The main factor is irrigation with two levels: the "well water", and "water stress". The secondary factor represented varieties which were completely randomized. Thus, a total of one hundred and twenty plastic pots (containers) were used including 60 pots for the "well water» and 60 pots for the "water stress". Plastic bags were used to wrap the pots after the phase of water saturation.

Pots with a capacity of 5 kg, were filled with soil and watered until the field capacity was reached. Varieties were sown on March 2nd, 2012 and plants were thinned to one plant per pot. After sowing, plants were regularly watered for a month. After soil saturation the pots were packed with plastic bags to avoid water loss through the surface of the soil, then weighed to get an initial weight at the beginning of the stress.

Table 1. List of sorghum genotypes used in the leaf conductance study

No	Cultivar	Origin	Specific traits
1	BT x 623	United States	Inbred line (parent of hybrid cultivar)
2	IS 18551	Ethiopia	Resistant to shoot fly
3	296 B	India	Disease-resistant (medium-maturity) sorghum B-lines
4	ICSV 745	India	Resistant to sorghum midge, downy mildew, ergot, and sugarcane aphid
5	PB 15881-3	India	Resistant to early shoot borer
6	PB 15520	India	Spotted stem borer resistant
7	N 13	India	Cultivated striga resistant landrace (post-germination striga resistance mechanisms)
8	IS 9830	Sudan	Striga resistant variety
9	E36-1	Ethiopia	Early drought resistant, Stay green landrace
10	M35-1	India	Postrainy landrace variety Tolerant to shootfly, charcoal rot and drought.
11	ICSV93046	India	Sweet sorghum with stalk sugar traits such as total soluble sugars or (Brix %), green stalk yield, juice quantity, girth of the stalk and grain yield
12	ICSR93024	India	Forage sorghum tolerant to acid soils

The pots were weighed every day in order to re water the plants according to their treatments: (i) for the water stress, plants were allowed to lose a maximum of 70 g on each day, meaning that any transpiration water loss above 70 g was added back; (ii) for the well water plants, watering was set to bring them back to about 80% field capacity, which was approximately 200 g below the field capacity weight of the first day. Thus, the daily weights obtained correspond to the plants transpiration of the day before. For this test, the weighing started 04/04/2012 and completed on 29/04/2012, which corresponds to the total drying of the pots (transpiration zero), following by the death of the stressed plants.

After weighing the pots, the amount of water needed for each plant was calculated before proceeding to the re-watering of the plants.

The transpiration calculation was done in the following way: weight of the day 1 minus the weight of the day 2 plus amount of water adjusted for the plant:

$$W.cal. = Wday1 – Wday2 + water\ addp1$$

Transpiration Efficiency (TE) is one of the physiological parameters that allows to evaluate the performance of a genotype in a selection of resistant genotypes in water deficit conditions. Plants were submitted to a progressive water stress by allowing them to lose a certain amount of water daily depending on the intensity of stress imposed. The water loss by plants every day led to a gradual decrease in soil in pots since pots were bagged to avoid water evaporation through the soil. The evaporation of the soil being zero, the weight loss was due to the transpiration of plants.

This transpiration was estimated from the difference of two successive weights of the pot, adding the quantity of water (water added) during the previous re-watering which is the equivalent of the plant daily transpiration minus the amount of water allowed to be lost per day. At the first transpiration deduction, the water (water added) was considered to be null.

At the end of the drydown experiment, i.e. when there was no longer any water available to support transpiration in the water stress treatment, plants were harvested and dried in an oven before assessing their dry weights.

The following formula was used for the TE determination:

$$TE = (FDM – MIDM)/TTW$$

TE: Transpiration efficiency of the plant
FDM: Final dry biomass of the plant
MIDM: Average initial biomass of the plant
TTW: Total transpiration from the plant during the period between the initial and the final weighing.

The parameters such as leaf weight, stem weight and root weight were also measured and the data were analyzed using the statistical software tool GenStat version 19.

3. RESULTS AND DISCUSSION

The relationship between the relative pot weight loss and the relative extractable water in the pot in 12 sorghum genotypes was significant with a high correlation coefficient (R^2= 0.7832). Since, the daily weights obtained correspond to the plants transpiration of the day before, the transpiration was correlated to the relative pot weight loss in genotypes (Fig. 1). More water is lost in the pot and this corresponded to the water amount used as the plants progressed in growth, increasing in the amount of biomass produced. Transpiration efficiency under water stress and well water conditions were correlated but the correlation coefficient was weak, in agreement with earlier results [7]. [7] showed that water extracted under well water and water stress conditions was poorly related. They also reported that total water uptake under water stress conditions varied among sorghum races. [8] reported genetic variation for water extraction under different types of water stress in different legumes and cereal crops.

Differences in TE have been reported in sorghum, although generally under well-watered conditions [9,10]. Other reports also show the existence of genotypic variation in TE under differing water regimes [11,12] in a work that included Tx7078, a genotype with low TE and assumed to be tolerant to pre-flowering drought [13].

Leaf weight, stem weight and root weight varied significantly between genotypes under well water conditions (Table 2). For the 3 variables measured, the mean values ranged from 8.39 to 12.51 g, 6.41 to 20.32 g and 7.57 to 9.15 g with a mean of 10.49, 11.59 and 8.53 g respectively. The heritability H^2 for leaf weight, stem weight and root weight was high with values of 0.90, 0.85 and 0.91 respectively. The genotype M 35-1 showed highest values for leaf weight (12.15 g), stem weight (21.19 g) and root weight (10.04 g) under well-watered conditions. The values for the genotype IS18551, N13 and IS 9830 were high for both stem weight and root weight.

Under water stress conditions only the stem weight measured was significantly different among the genotypes ranging from 5.87 to 9.40 g with a mean of 7.14 g and a heritability H^2 = 0.71 (Table 3). The genotype M35-1 showed the highest stem weight under water stress conditions followed by N13 and IS 18551. The high significance of the stem weight under water stress conditions suggests a close interaction between the environment conditions and the genotypic response to drought, leading to GxE variations for stem weight. [14] indicated that

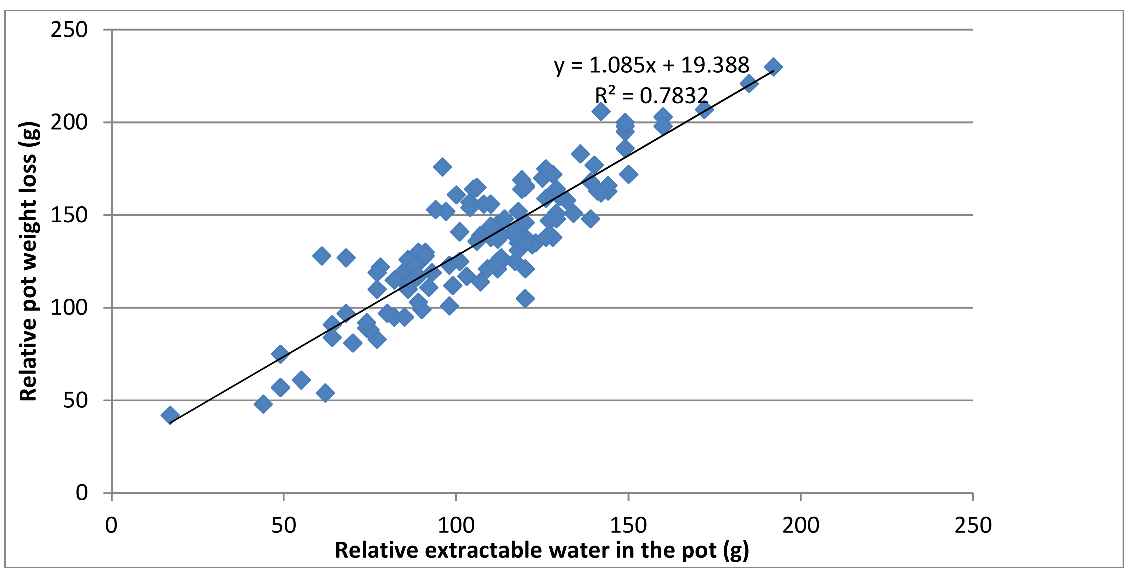

Fig. 1. Variation of relative pot weight loss (g), as a function of relative extractable water (g) in the pot in 12 sorghum genotypes

Table 2. Mean of leaf weight, stem weight and root weight of sorghum genotypes studied under well-watered conditions

Environment	Entry	Genotype	Leaf Weight (g)	Stem Weight (g)	Root weight (g)
Well water	1	BT x 623	8.02	5.89	5.53
Well water	2	PB 15881-3	8.78	7.15	6.85
Well water	3	296 B	11.57	9.46	9.64
Well water	4	ICSV 745	11.11	8.92	8.21
Well water	5	IS 18551	11.29	17.98	8.53
Well water	6	PB 15520	12.86	10.30	9.37
Well water	7	N 13	11.34	12.29	10.46
Well water	8	IS 9830	8.17	12.53	9.85
Well water	9	E36-1	11.23	11.36	9.06
Well water	10	M35-1	12.15	21.19	10.04
Well water	11	ICSV93046	10.16	11.39	7.94
Well water	12	ICSR93024	9.19	10.66	6.91
Min			8.39	6.41	7.57
Mean			10.49	11.59	8.53
Max			12.51	20.32	9.15
Mean SED			174.75	0.86	1.82
Mean LSD			351.36	1.74	3.67
Heritability			0.90	0.85	0.91
p-value			0.000	0.000	0.000

Environment	Entry	Genotype	Leaf_Weight gm_Means_B LUEs	Stem_Weight gm_Means_B LUEs	Root_Weight gm_Means_ BLUEs	Leaf_Area sq cm_ Means_ BLUEs
WW	1	BT x 623	8.02	5.89	5.53	2079
WW	2	PB 15881-3	8.78	7.15	6.85	2139
WW	3	296 B	11.57	9.46	9.64	2805
WW	4	ICSV 745	11.11	8.92	8.21	2398
WW	5	IS 18551	11.29	17.98	8.53	2140
WW	6	PB 15520	12.86	10.30	9.37	3205
WW	7	N 13	11.34	12.29	10.46	2458
WW	8	IS 9830	8.17	12.53	9.85	1888
WW	9	E36-1	11.23	11.36	9.06	2653
WW	10	M35-1	12.15	21.19	10.04	2638
WW	11	ICSV93046	10.16	11.39	7.94	1985
WW	12	ICSR93024	9.19	10.66	6.91	2299
Min			8.39	6.41	7.57	1940
Mean			10.49	11.59	8.53	2391
Max			12.51	20.32	9.15	3120
Mean SED			174.75	0.86	1.82	1.75
Mean LSD			351.36	1.74	3.67	3.52
Heritability			0.90	0.85	0.91	0.32
p-value			0.000	0.000	0.000	0.17

stem characters, especially stem diameter, may play an important role in sustaining grain filling under such conditions. This is possibly due to a greater stem capacity for assimilates storage post-anthesis and subsequent remobilization to the grains. Stem soluble carbohydrates is known to play an important supporting role for grain yield in wheat for instance, and the same may happen here. M35-1, originated from India, is known as a postrainy landrace variety tolerant to shootfly, charcoal rot and drought.

The difference of genotypes stem weight under water stress compared to well water conditions suggested that drought tolerance may be adaptive since its important role in accumulation of assimilates storage for vegetative growth and grain filling. These results agree with findings on groundnut reported by several authors [15,16,17].

The statistical analysis showed significant differences between different genotypes for leaf canopy conductance (Fig. 2). The leaf canopy conductance varied in value from 0.0459 to 0.0882 µmol m^{-2} s^{-1}. Genotypes IS 9830 (0.0882), IS 18551 (0.0814), M35-1 (0.0752) and ICSV93046 (0.0722) showed the highest leaf canopy conductance values contrary to the genotypes: PB 15520 (0.0473) and BT x 623 with 0.0459 (Fig. 2). The leaf canopy conductance under well-watered conditions was weakly correlated to the stem weight (0.360) and root weight (0.179). The same pattern was observed in water stress conditions with a correlation of 0.178 and 0.497 with the stem and root weight respectively. This study showed a relationship between leaf canopy conductance and stem and root weight.

Table 3. Mean of leaf weight, stem weight and root weight of sorghum genotypes studied under water stress conditions

Environment	Entry	Genotype	Leaf_Weight_ gm_Means_ BLUEs	Stem_Weight_ gm Means BLUEs	Root_Weight_ gm_Means_ BLUEs
WS	1	BT x 623	8.27	6.21	6.03
WS	2	PB 15881-3	8.58	5.95	7.55
WS	3	296 B	8.87	6.13	6.06
WS	4	ICSV 745	8.72	6.72	7.15
WS	5	IS 18551	8.07	8.23	6.92
WS	6	PB 15520	9.34	6.77	6.59
WS	7	N 13	10.12	8.45	7.34
WS	8	IS 9830	8.92	6.68	8.24
WS	9	E36-1	8.59	5.36	6.31
WS	10	M35-1	8.53	10.31	6.23
WS	11	ICSV93046	7.17	7.61	5.75
WS	12	ICSR93024	7.19	7.30	5.94
Min			8.02	5.87	6.57
Mean			8.53	7.14	6.68
Max			9.13	9.40	6.85
Mean SED			0.92	1.03	1.02
Mean LSD			1.84	2.07	2.05
Heritability			0.38	0.71	0.11
p-value			0.128	0.001	0.362

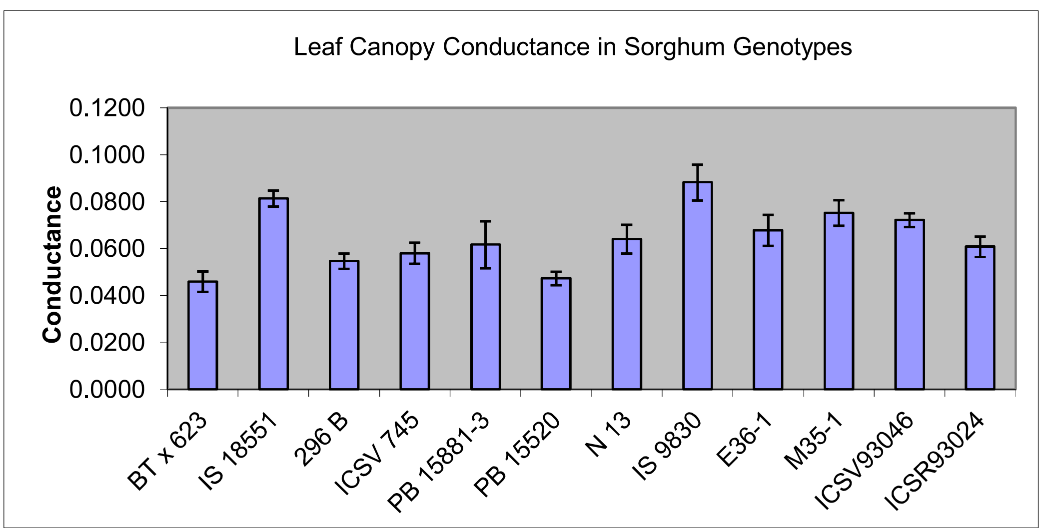

Fig. 2. Leaf canopy conductance of the 12 sorghum genotypes studied

Table 4. Analysis of variance of leaf weight in water stress and well water conditions

Environment	Genotype	Mean	
WS	ICSV93046	7.172	a
WS	ICSR93024	7.194	a
WW	BT x 623	8.024	ab
WS	IS 18551	8.074	ab
WW	IS 9830	8.174	ab
WS	BT x 623	8.266	ab
WS	M35-1	8.534	abc
WS	PB 15881-3	8.582	abc
WS	E36-1	8.588	abc
WS	ICSV 745	8.718	abc
WW	PB 15881-3	8.780	abc
WS	296 B	8.866	abc
WS	IS 9830	8.916	abc
WW	ICSR93024	9.192	abcd
WS	PB 15520	9.338	abcd
WS	N 13	10.124	abcd
WW	ICSV93046	10.158	abcd
WW	ICSV 745	11.106	bcd
WW	E36-1	11.234	bcd
WW	IS 18551	11.292	bcd
WW	N 13	11.344	bcd
WW	296 B	11.574	bcd
WW	M35-1	12.150	cd
WW	PB 15520	12.858	d
CV (%)		16.07	
Standard error		1.529	
LSD (5%)		1.919	

WS: water stress; WW: well water

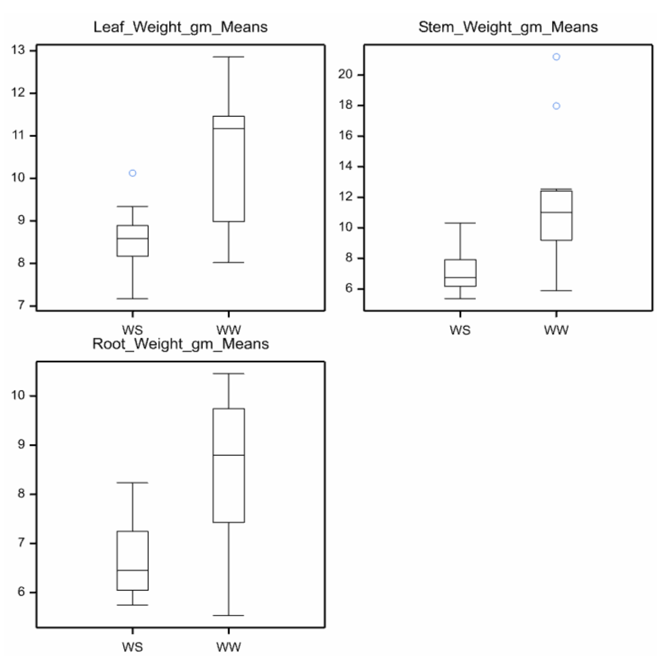

Fig. 3. Variability in means of leaf weight, stem weight and root weight under well-watered and water stress conditions

Table 5. Analysis of variance of stem weight in water stress and well water conditions

Environment	Genotype	Mean	
WS	**E36-1**	**5.362**	**a**
WW	BT x 623	5.888	ab
WS	PB 15881-3	5.954	ab
WS	296 B	6.130	ab
WS	BT x 623	6.210	ab
WS	IS 9830	6.684	abc
WS	ICSV 745	6.718	abc
WS	PB 15520	6.768	abcd
WW	PB 15881-3	7.148	abcd
WS	ICSR93024	7.302	abcd
WS	ICSV93046	7.612	abcd
WS	**IS 18551**	**8.226**	**abcd**
WS	N13	8.452	abcd
WW	ICSV 745	8.918	abcd
WW	296 B	9.460	abcd
WW	PB 15520	10.296	abcd
WS	M35-1	10.314	abcd
WW	ICSR93024	10.656	abcd
WW	**E36-1**	**11.356**	**bcd**
WW	ICSV93046	11.388	bcd
WW	N 13	12.292	cde
WW	IS 9830	12.532	de
WW	**IS 18551**	**17.982**	**ef**
WW	M35-1	21.194	f
CV (%)		24.99	
Standard error		2.341	
LSD (5%)		2.939	

WS: water stress; WW: well water

The Fig. 3 showed the variability and overall means of leaf weight, stem weight and root weight under water stress conditions were smaller than the means of these variables under well-watered conditions.

The analysis in both environments, stress and well water, showed significant differences between genotypes for leaf weight (Table 4) and stem weight (Table 5). The analysis did not show significant differences for root weight among genotypes. Table 5 indicated only two genotypes E36-1 and IS 18551 showing significant differences in stress vs well water conditions for stem weight.

4. CONCLUSION

This preliminary study reports a large variation for plant stem under water stress conditions. Water use by the plant was limited by soil water availability. Also, this study showed a relationship between leaf canopy conductance and stem and root weight. There were also differences in the leaf canopy conductance, which could be used further to test the response to water stress of these contrasting genotypes.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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