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Full Length Research

Identification of Drought Tolerant Sorghum Genotypes in Aweil (Nyamliel, Gog Machar) and Tonj South Rain fed Areas of South Sudan

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These studies were conducted for two seasons (dry and rain seasons) during 2016/2017cropping season at Nyamliel Agricultural Demonstration and Learning Centre, NADLC and the University of Juba. The objectives were to identify stress tolerant/ or resistant traditional sorghum land races to both drought and high moisture conditions that are locally cultivated in Tonj South: GPS coordinates N 070 18.328'; and E 028045.533'), Nyamliel and Gog Machar (Aweil). Eight sorghum genotypes 5 from Nyamliel evaluated at (Aweil) and 3 from Tonjplus the 5 from Aweil evaluated at the University of Juba namely, Rapchol, Yar, Rapheir (Contrl-1), Malwal, Luel, Aher (Contrl-2), AdhalRwuait and Acholkol. These genotypes were evaluated under five irrigation regimes of: 2DI (two day intervals); 7DI; 10DI; 15DI and 30DI, respectively. Results showed sorghum genotypes namely, Yar, Malwal, Rapher and Aher as superior and out yielded genotypes Luel and Acholkol and the other entries at ($P \leq 0.05$) under drought conditions. Conversely, under water-logged conditions the yields of all eight tested genotypes were not significantly different from each other ($P \leq 0.05$). The study concluded that in the areas covered by the study namely, Aweil (Nyamliel and Gog Machar), and Tonj South within the traditional sorghum germplasm there are materials with good traits that are tolerant to both excess (high) and (low) levels of moisture stress. Furthermore, the study recommends another similar exercise to include an extended range of sorghum genotypes in this and neighboring areas so as to widen the spectrum of tolerant genotypes/ varieties to high/low moisture stresses and the introduction of exotic high yielding genotypes from similar environments as tools to build resilience and adapt to the effects of climate change and improve crop productivity thus, striving to build and maintain resilient and food secure communities in South Sudan.

Keywords: Sorghum spp.; genotypes; drought tolerance; excess moisture; irrigation regimes; South Sudan

INTRODUCTION

Sorghum, *Sorghum bicolor*(L.)Moench is an important staple food grain in the world and comes third after wheat, rice and maize. In South Sudan, it is one of the most important staples especially in the Northern States (former Bahr el Ghazal and Upper Nile regions) and some states in parts of former Equatorial region where it competes with Maize (*Zea mays* L.) and Cassava (*Manihot esculenta Crantz*).There are no exact figures of production however, it's believed to be substantially high. However, being a poor man's food sorghum production and farming is highly characterized by traditional farming practices, with no or low inputs thus, operating at the margin of subsistence and the high rate of use of traditional varieties/ land races as stipulated by Ceccarelli (2016), El-Fathi (1999) and Gowda et al. (2000b). These practices have plagued the production of sorghum and other millets over the years which has since remained very low and average yields to date are below 1 ton/ha. Any yield increases are usually attributed to horizontal increases in land area and most farmers have not benefited much from high yielding varieties being grown elsewhere (Ojulong et al., 2017; FAO/OECD, 2012; Gowda et al., 2000a, b).

The sorghums and millets have founded civilizations and are staples for many; they are by far the most drought tolerant grain crops known. They are believed to have originated in Eastern Africa around 3000 BC (Bjonstad, 2012). It ranks fifth amongst the world's cereals with a production of 65 million and is grown in about 98 countries with the USA at the top (18%). ICRISAT (1999) listed other production countries namely, India, China, Mexico, Sudan and Argentina. Sorghum has numerous races based on the huge diversity in its external appearance the genome sequenced in 2008 counts 0.8 billion base pairs, twice that of rice and one third that of maize (Bjonstad, 2012). Yields in Africa and most third world countries continue to be relatively low due to the dependency on the use of land races and traditional production methods; coupled by the unfavorable effects of climate change which is characterized by the excesses of moisture or extreme drought conditions. The present studies were therefore, incepted to address a selection process at the farmers level in line with Ceccarelli, 2016; Ceccarelli et al.,(2010); McGuire and Sperling, (2011; 2013) for highly tolerant or resistant traditional sorghum or(heirloom) varieties. Such genotypes if identified have good in built acquired adaptability preparedness drawn over the years and have high resilience to drought, water logging and stable yields under harsh environments (Gowda et al., 2000a). This would be a useful tool in the face of the changing climatic conditions and positively address the issues of food insecurity and the perennial grain deficit experienced in the country, South Sudan.

MATERIALS AND METHODS

Field trials and location

Experiment 1: A trial was conducted during off or dry season at Nyamliel Agricultural Demonstration and Learning Centre (NADLC)located at (GPS coordinates N 090 07.071' and E 0260 59.384').

Experiment 2: This was conducted at the University of Juba Department of Agricultural Sciences Nurseryin 20L capacity pots located at Lat. $4^0$84' N, and Long. $31^0$5'Ealso during the dry season.

Experiment 3: This trial was conducted at the University of Juba during the rainy season and was directly planted in the field under rain fed conditions.

Experimental materials, land preparation and field layout

Sorghum genotypes: For experiment 1, The entries consisted of 5 sorghum genotypes (T1-T5) collected from Aweil (Nyamliel and Gog Machar) and planted at NADLC, located at Latitude N 090 07.071' and Longitude E 0260 59.384', under irrigation. Another 3 sorghum genotypes (T6-T8) collected from Tonj West were combined with the 5 NADLC sorghum genotypes and were planted at University of Juba Nursery under rain fed conditions (Experiment 3). For both the irrigated field experiments at NADLC and rain season trials at University of Juba, plot size was one single row of 2m length and plants were spaced 30cm within a row and rows were spaced 0.75m apart. The same entries (8 sorghum genotypes) used in experiment 3 were used in experiment 2.The treatments consisted of the following:-

Sorghum genotypes: Genotypes T1-T5 are from Aweil (Nyamliel and Gog Machar area) and T6-T8 from Tonj South- GPS coordinates N 070 18.328'; E 0280 45.533'.

T1-	Rapchol	T5-	Luel
T2-	Yar	T6-	Aher Contrl-2 (Tonj)
T3-	Rapheir Contrl-1 (Nyamliel)	T7-	AdhalRwuait
T4-	Malwal	T8-	AcholKol

Irrigation regimes: For the irrigated trials (Experiments 1 and 2) five irrigation regimes in day intervals (DI's) were used namely, 2DI, 7DI, 10DI, 15DI and 30DI. 7DI was taken as control and this theoretically was intended to have zero plant cell water potential (where soil is at field capacity).

Design, data collection and analysis

At all locations, the trials were laid out in a randomized complete block design and arranged in a 5x3x5 factorial:5 varieties x 3 replicates x 5 irrigation regimes) at NADC and 8x3x5: 8 genotypes x 3 replicates x 5 irrigation regimes) at University of Juba according to the methods of Gomez and Gomez (1984) or Quinn and Keough (2002). Data were collected on some agronomic parameters including: plant height (cm), Mean number of leaves per plant (MNL/P); leaf area (LA) and leaf area index (LAI) determined by the empirical relationship according to Marshal(1968).

LAI = [LA x NLp x NPs]/ AS

Where: NLp = the average number of leaves per plant, (obtain the mean from 5 plants plot = 15 plants/plot); NPs = the average number of plants per subplot, and AS = area of subplot expressed in cm.

Also, shoot biomass (gm), and drought resistance index DRI that attempts to evaluate the yields of crops in relation to variable moisture stress levels and drought conditions while eliminating genotypes with characteristics of drought escape as stipulated by Fisher and Maurer (1978) and Bidinger et al. (1982) were derived from the following relationship: -

DRI = [Ys/Yn] / [Ms/Mn]

Where, Ys and Yn are the genotype yields (or biomass) under stress and non-stress respectively and Ms and Mn are the mean yields (or biomass) over all genotypes in the given test under stress and non-stress conditions, respectively.

An evaluation of some pathological production constraints was taken if and when encountered. Data was analyzed by the statistical software MSTATC and means separated by Duncan's Multiple Range Test, DMRT at ($P \leq 0.05$) and results interpreted accordingly. Where necessary data were subjected to clustering either by Past software/ or NCSS11as per the methods of Romesburg (1984).

RESULTS AND DISCUSSION

The data on some agronomic parameters and yield (shoot biomass) under rain fed are presented in Table1. Sorghum genotypes Rapchol, Yar, Rapheir and Malwal had significantly higher yields ($P \leq 0.05$) compared to the other four genotypes the trend was similar for plant height and leaf area. Meanwhile, Table 2 and Table 3show the drought resistance indices for the trials at University of Juba (8 genotypes) and Nyamliel (NADLC)(5 genotypes), respectively. Sorghum genotypes with a DRI score of above unity (1.0) are considered suitable for the particular stress under investigation either excess moisture or drought conditions. Therefore, in Tables 2 and 3, varieties Rapchol, Malwal, Luel, Aher, and Rapher with DRI of 1.12, 1.08, 1.26, 1.25 and 1.89 are the best varieties suited for water logged conditions as demonstrated by Bidinger, et al., (1982) and Witcombe, (2003) who stated that varieties with DRI above 1.2 are suitable for stress tolerance. On the other hand, drought resistance was apparent in varieties Rapchol, Yar, and Rapher which were best at 30DI; Rapchol, Malwal, Rapher and Luel at 15DI and no varietal differences were observed for yield at 10DI. It should be noted that most of the varieties that appeared as water logged and drought resistant also performed well under normal conditions. The column under 2DI was assigned a negative sign to indicate it is on the left side (high moisture stress) of the standard 7DI which was assigned an index of unity (1.0) to compensate for unforeseen irrigation errors which was not overlooked in the trials since no soil moisture meter was used to maintain the plant cell water potential at zero (field capacity) during the course of the trials.

Table 1: Some yield and agronomic parameters for eight sorghum varieties tested under rain fedconditions (rain season trials- Expt. 3) at the University of Juba.

Sorghum variety	Plant height (cm)	MNL / plant	LA (Leaf area) (cm2)	LAI (Leaf area index)	DM (g) (Biomass)
T1- Rapchol	156.83 b	6.67 ab	417.99 a	2.0 a	104.1 bc
T2- Yar	212.17 a	6.33 ab	362.81abc	2.9 a	196.2 a
T3- Rapheir Contrl-1	211.33 a	7.67 a	380.39 ab	2.7 a	115.63 b
T4- Malwal	182.33 ab	7.0 ab	290.30 bcd	2.4 a	88.5 bc
T5- Luel	164.67 b	6.67 ab	267.80 cd	1.9 a	34.5 c
T6- Aher Contrl-2	154.67 b	6.33 ab	204.88 de	2.0 a	37.37 c
T7- AdhalRwuait	147.50 b	5.0 b	198.92 de	2.7 a	29.67 c
T8- AcholKol	146.83 b	6.33 ab	156.94 e	3.1 a	26.13 c
GM	**172.04**	**6.50**	**285.04**	**2.46**	**79.01**
CV (%)	14.47	16.32	18.74	35.25	51.61
SE ($\pm$)	88.0	0.37	18.80	0.3	14.41
Significance	*	*	*	ns	*

Key: Plant height (cm); LA = leaf area; LAI = Leaf area index; MNL = mean number of leaves per plant; DM = dry matter (biomass); (*) = significant at ($P \leq 0.05$); ns = not significant. Means in a column followed by the same letter(s) are not significantly different according to Duncan's multiple range test (DMRT).

Table 2: Drought resistance indices for five irrigation regimes and eight sorghum varieties tested derived from dry season trials at University of Juba, 7DI is treated as standard (Experiment 2).

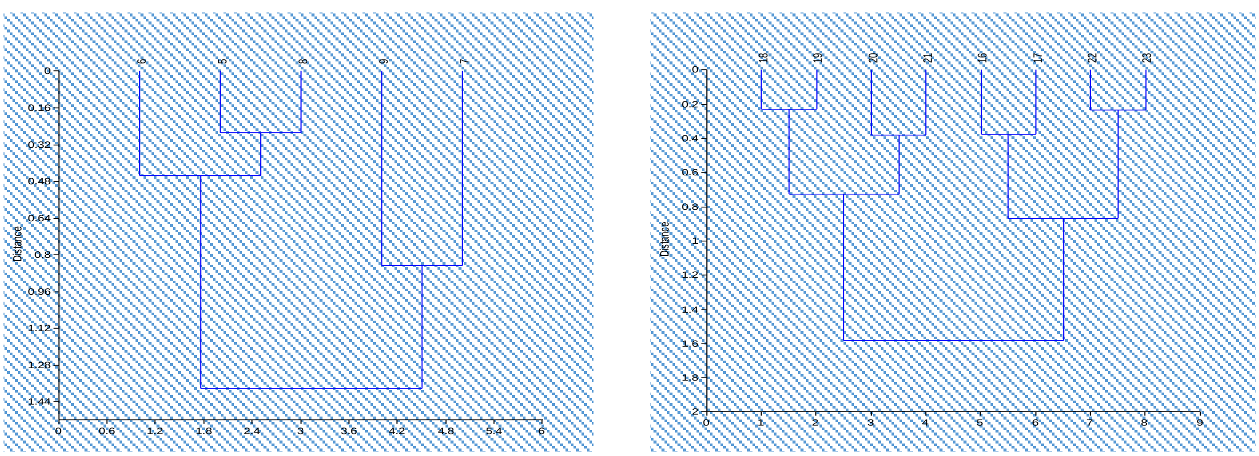
Sorghum variety	**Irrigation intervals (days)**				
	2DI	**7DI**	**10 DI**	**15 DI**	**30 DI**
T1-Rapchol	(-) 1.12	1	0.81	1.02	1.54
T2- Yar	(-) 0.79	1	0.81	0.71	1.25
T3 Rapheir Contrl-1	(-) 0.97	1	1.44	1.21	1.10
T4- Malwal	(-) 1.08	1	1.19	1.03	1.05
T5- Luel	(-) 1.26	1	1.53	1.06	0.88
T6- Aher Contrl-2	(-) 1.25	1	1.92	0.69	0.84
T7- AdhalRwuait	(-) 0.79	1	0.88	0.83	0.65
T8- AcholKol	(-) 0.87	1	0.75	0.54	0.72

Key: (-) = DRI due to water excesses, negative sign is only to indicate figure is on left (high moisture) side from the standard, 7DI; (1) = indices assigned for standard treatment of no stress; DI = irrigation intervals in days.

Table 3: Drought resistance indices for five irrigation regimes and five sorghum varieties tested derived from dry season trials at Nyamliel, 7 DI is treated as standard (Expt.1).

Sorghum Genotype	**Irrigation intervals**				
	2DI	**7DI**	**10 DI**	**15 DI**	**30 DI**
T1- Rapchol	(-) 0.69	1	1.0	0.96	0.86
T2- Yar	(-) 0.84	1	1.1	0.69	1.12
T3 Rapheir Contrl-1	(-) 1.89	1	1.75	1.23	1.16
T4- Malwal	(-) 0.96	1	0.75	0.91	0.77
T5- Luel	(-) 1.03	1	1.0	1.44	0.85

Key: (-) = DRI due to water excesses, negative sign is only to indicate figure is on left (high moisture) side from the standard, 7DI; (1) = indices assigned for standard treatment of no stress; DI = irrigation intervals in days.



A) Five varieties from Aweil (Nyamliel)

Definition of leaves: Variety 5 = (Rapchol), 8 = (Malwal); 6= (Yar); 7= (Rapheir) and 9= (Luel).

B) A mix of eight varieties (5 from Nyamliel and 3 from Tonj)

Definition of leaves:18= (Rapheir); 19= (Malwal); 20= (Luel); 21= (Aher); 22= (AdhalRwuait), 23= (Acholkol); 16= (Rapchol) and 17= (Yar).

Figure 1: Phylogenetic trees constructed from drought resistance indices across five irrigation regimes for A) five sorghum varieties from Nyamliel and B)combination of eight sorghum varieties from both Nyamliel and Tonj by Wards method.

Figure 1A. Show the distribution of varieties across the different irrigation regimes taken as variables and varieties as cases at Nyamliel, NADC. Variety 5 (Rapchol) and 8 (Malwal) occur in cluster I at a distance of 0.24 and variety 6 (Yar) in cluster II at a distance of 0.48; cluster III contains varieties 7 (Rapheir) and 9 (Luel) at a distance of 0.8 and cophenetic correlation coefficient of 0.60. Meanwhile, in Fig. 1 B. the eight varieties were grouped into IV clusters spread out into two main sub clusters or groups: one contains varieties 18 (Rapheir) and 19 (Malwal) clustered together at a distance of 0.2 in cluster I and varieties 20 (Luel) and 21 (Aher) clustered at the distance of 0.4 in cluster II; and this two groups exhibited similarities to each other at a distance of 0.7. The other sub-group contains variety 22 (AdhalRwuait), 23 (Acholkol) in cluster III and varieties 16 (Rapchol) and 17 (Yar) at a distance of 0.4 were in cluster IV and these all exhibited similarities at a distance of 0.8, and cophenetic correlation coefficient of 0.66, respectively.

The suitability of farmer based participatory selection from enormous diversity of traditional 'hairloom' varieties has been well documented (Ojulong et al., 2017; Cerraceli, 2016; D'Agostino et al., 2011). and its implication in the preservation of plant germplasm over the rather conventional breeding methods which were extensively used over the years. Although it is characterized by higher yields per unit area and was main driver in the green revolution era it also has had its adverse effects both on the environment and more so in the great loss of useful plant germplasm and diversity coupled by the emergence of several plant production constraints like pests and plant diseases gaining a change in status from minor to major pests' due to the more uniform crop plants grown that were derived from breeding programs targeting specific or particular traits of interest, like high yields, uniformity etc., vertical resistance to targeted pests/ diseases which further eroded genes and furthered the objectives of the green revolution. The findings elucidated in this work is location specific therefore, is well suited and in line with work done elsewhere (Maheswari et al., 2015; McGuire and Sperling, 2013; Gowda et al., 2000b). Thus, providing a way out for adaptation to climate change by offering the basis for resilient seeds, resilient crops and finally building resilience in farm communities and eventually leading to improved food security status as articulated by D'Agostino (2011). Therefore, there is need to scale up on the findings at hand. This study further intends to trigger informed responses to resilience and seed systems in South Sudan a country that has been relying extensively on seed aid since 2005 with half the farming community receiving aid at an average of 1.8 times and some as many as 12 in 2010 (McGuire and Sperling, 2013); thus, seed systems remain extensively in the hands of humanitarian actors.

CONCLUSION AND RECOMMENDATIONS

Conclusions

From the findings of this study we can conclude that:

In the areas covered by the study namely, Aweil (Nyamliel, Gog Machar) and Tonj west there are in existence local sorghum genotypes that are both drought and water-logged conditions resistant/ tolerant which therefore, makes this varieties candidate varieties in the fight to identify resilient crops in the face of climate change as a precursor to build resilient and food secure communities.

More work is needed to widen the spectrum of genotypes in tests to elucidate greater numbers of more high yielding and stable genotypes/ varieties.

Recommendations

i. A wider study should be conducted to include most drier parts or States in the country so as to inventory most of the varieties with good traits of resilience to the changing climatic conditions; and ensure adaptation.

ii. Introduction of higher yielding varieties from similar environments to improve yields and improve food security conditions in the country, it should however, be noted that one major constraint to adoption of improved varieties is inadequate access to seed; therefore, seed multiplication, distribution should be in same package.

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