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Genotype × environment interaction on biomass production in sorghum (*Sorghum bicolor* L. Moench) in North-Western Nigeria

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Genotype x environment interaction was determined from a field experiment conducted to evaluate sorghum landraces of North Western Nigeria during the 2010 rainy season at Usmanu Danfodiyo University, teaching and research farm, Sokoto, Sokoto State and during 2011 rainy season at Bubuche, Augie Local Government Area, Kebbi State, North-Western Nigeria. The materials used in the study consisted of ten indigenous grain sorghum genotypes representing the types widely grown in North-Western Nigeria. The treatments were laid out in a Randomized Complete Block Design (RCBD) and replicated three times. Data were collected on sorghum traits in accordance with the procedure outlined in the IBPGR/ICRISAT sorghum descriptor. The study revealed that genotype by environment interaction had significant influence on only plant height (6804.4), leaf area index (0.86*) and flag leaf length (67.99*). Indicating that selection for plant height, flag leaf length and leaf area index is environment dependent. However, leaf number (8.68), leaf length (96.44), flag leaf area (3131.93), straw weight (3.8), 100-seed weight (34.68), and total grain yield (1233080) recorded non significant G x E influence. Selection for these traits can therefore be carried out across the two environments.**

Key words: Biomass, environment, genotype, influence, sorghum.

INTRODUCTION

Sorghum (*Sorghum bicolor* L.) Moench is a staple food crop for millions of poor in the semi-arid tropics (SAT) and is adapted to a wide range of environmental conditions. It is suitable for cultivation in semi-arid and arid areas of the world even in areas where rice, wheat and corn are difficult to grow (Ezeaku et al., 1997). The crop has better drought tolerance than most other field crops and significant variation exists within the species (Walulu et al., 1994). As a warm-season crop (C4 photosynthetic pathway), it is a short-day annual grass, growing best under relatively high temperatures and under sunny conditions (Newmann et al., 2010).

Sorghums in general can be classified into two types: Forage types (mainly for forage or animal feed) and grain types (mainly for human consumption). The forage sorghums are further grouped into four types: (a) hybrid forage sorghum, (b) sudan grass, (c) sorghum x sudan hybrids (also known as sudan hybrids), and (d) sweet sorghum. The latter is used mainly for molasses but more recently for biofuel production as well (Newmann et al., 2010).

In 2011 the world grain production of sorghum was 4,198,010 tonnes, with an average yield of 15, 274 kg/ha over 35,482,800 ha (FAOSTAT, 2011). In Africa

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20,780,959 tonnes were produced at an average yield of 10,623 kg/ha across 19,561,929 ha during the same period. Nigeria was ranked second in sorghum production worldwide after India in 2011 (FAOSTAT, 2011), with production of 6,897,060 tonnes, harvested from 4, 891,150 ha at with an average yield of 14,101 kg/ha.

Sorghum as a crop originated as far back as 3,000 years ago. The selection in those early times was for grain more than for forage. However, selection for forage varieties has been occurring for the last hundred years. Forage sorghums are similar to grain types but are taller and have higher forage quality (Newmann et al., 2010). Forage sorghums are used primarily as silage for livestock. They are sometimes grown and harvested with soybeans to improve the protein content of the silage. Sudangrasses and sorghum- sudangrass hybrids are grazed by livestock or fed as green chop or hay (Doggett, 1988). However, irrespective of the cultivar, Fontaneli et al. (2001) determined a 134 to 150 g kg^{-1} concentration of crude proteins in sorghum. However, green mass and dry matter yields and nutritional value of forage sorghum depend on the development stage at which cutting was carried out (Pospisil et al., 2009).

The prevalence of environmental causes of variation over the genetic effects does not suggest that the importance of genotype should be minimized (Faisal and Aisha, 2011). However, global warming and climatic changes were directed to reduce the productivity of many crops around the world. So that a considerable attention should be given to the effect of genotype- environment interaction in the plant breeding programs especially in the developed countries (Ghazy.Mona et al., 2012). Developing high yielding cultivars is mainly depending upon existing genetic variation among the germplasm under existing breeding programs. The relative performance of cultivars for quantitative traits such as yield and the other characters, which influence yield vary from an environment to another. Consequently, to develop a variety with high yielding ability and consistency, high attention should be given to the importance of stability performance for the genotypes under different environments and their interactions (Ghazy.Mona et al., 2012). The interaction between genotype and environment had an important bearing on breeding for better varieties (Allard and Bradshaw, 1964). Genotype x Environment interaction can be defined as the differential response of varying genotypes under change(s) in the environment (Mather and Caligari, 1976). It refers to instances where the joint effects of genotype and environment are significantly greater or significantly reduced, than would be predicted from the sum of the separate effects (Andrew et al., 1998). In order to exploit the existing variability and develop new high yielding cultivars, sorghum improvement efforts under diverse environmental conditions are needed (Faisal and Aisha, 2011).

The objective of the study was to investigate the influence of genotype by environment interaction on biomass production of sorghum in semi arid North Western, Nigeria.

MATERIALS AND METHODS

Ten local sorghum landraces were evaluated during the rainy seasons of 2010 at Usmanu Danfodiyo University, teaching and research farm, Sokoto, Sokoto State and during 2011 rainy season at Bubuche, Augie Local Government Area, Kebbi State, in North-Western Nigeria. Sokoto is located in the Sudan Savanna agro-ecological zone of Nigeria on latitude 13° 01 N; longitude 5° 15 E and altitude of about 350 m above sea level (ASL). Mean annual rainfall is about 752 mm. The minimum and maximum temperatures are 26 and 35°, respectively, and relative humidity of 23 to 41%. The area is characterized by long dry season with cool air during Hammattan (November – February), dry air during hot season from March to May followed by a short rainy season (Bello, 2006) and Bubuche is located in Augie local government area of Kebbi State on latitude 13° 05 N ; longitude 4°12 E and altitude of 345 m above the sea level; temperature ranges from 27 to 34° and relative humidity of 24 to 44% with mean annual rainfall of 6700 to 7600 mm (Kebbi State, 2009). The texture of the soil was loamy sand and the soil is deep, loose and well drained. Chemical analysis shows that the soil is slightly acidic, low to medium in organic carbon, low total nitrogen, low exchangeable cations low in cations exchange capacity (CEC), very low available P and K Ca and Mg contents and low bulk density (Table 1).

The materials used in the study consisted of ten indigenous grain sorghum genotypes representing the types widely grown in North-Western Nigeria, which were collected by the National Center for Genetic Resources and Biotechnology (NACGRAB), Moor plantation, Ibadan, Nigeria (Table 2).

The experiment was laid out in a Randomized Complete Block Design (RCBD) and replicated three times. Each plot size was 6 m × 3 m, 75 cm as inter row spacing and intra-row spacing of 30 cm and a total of 240 plants per plot after thinning were maintained. Before sowing, seeds were treated with Apron-plus 3 g/kg seed against soil fungi and insects. Sowing was taken up on 10th of June, 2010 and 2011. Five seeds were sown in each hill. Seedlings were thinned to three plants per hill after three weeks from sowing. Hand hoeing was done twice to control weeds, weeding at two weeks and the subsequent weeding three weeks later.

Data collection

Data was recorded for days to 50% flowering (DF), plant height (PH), and leaf characteristics that included leaf length (LL), leaf number (LN), leaf area index (LAI), flag leaf area (FLA) and flag leaf length (FLL). At maturity, total grain yield (TGY), 100-grain weight (HGW) and straw weight (STRAW-WT) were recorded at both locations and during both seasons in accordance with the procedure outlined in the IBPGR/ICRISAT sorghum descriptor (IBPGR and ICRISAT 1993). LAI was calculated on the basis of the length and width of the third leaf from top multiplied by the coefficient of 0.71(Krishnamurthy et al., 1974). Data collected was subjected to analysis using SAS ver. 9.1 (SAS, 2004) to estimate variance for all traits.

RESULTS AND DISCUSSION

Results of the study revealed that significant (P ≤ 0.05) differences exists between the varieties with respect to all

Table 1. Physical and chemical properties of the soil at two experimental sites (Sokoto, 2010; Bubuche, 2011) cropping seasons.

S/N	Properties	Sokoto, 2010	Bubuche, 2011
Physical properties			
1	Sand (g kg^{-1})	890	517
2	Silt (g kg^{-1})	45	377
3	Clay (g kg^{-1})	43	103
4	Textural class	Sand	Sandy loam
Chemical properties			
5	Soil pH (H_2O) 1:2	5.90	5.80
6	Soil pH ($CaCl_2$) 1:2	5.40	5.30
7	Organic carbon (g kg^{-1})	2.40	1.76
8	Total nitrogen (g kg^{-1})	0.40	0.66
9	Available P (mg kg^{-1})	0.80	0.76
10	Exchangeable K (Cmol kg^{-1})	0.44	0.58
11	C.E.C. (Cmol kg^{-1})	5.50	11.80
12	Na (Cmol kg^{-1})	0.43	0.50
13	Ca (Cmol kg^{-1})	0.35	0.31
14	Mg (Cmol kg^{-1})	208	0.51

Source: Agric. Chemical Lab. UDUS.

Table 2. Sorghum landraces used in the study.

S/N	Name	Area collected	Grain colour	Major use
1	Zago.Ex-BATSARI	Katsina State	Brown	Food
2	NG/SA/07/005	Niger State.	White	Food
3	NG/SA/07/125	Zamfara State	White.	Food
4	NGB/06/001	Kaduna State	White	Food
5	NG/SA/DEC/07/0049	Niger State	White	Food
6	NG/SA/DEC/07/0108	Niger State	White	Food
7	NG/SA/DEC/07/0213	Kaduna State	White	Food
8	NG/SA/DEC/070123	Kano State	White	Food
9	NG/SA/DEC/07/0036	Niger State	White	Food
10	EX-ARGUNGU (Kaura)	Kebbi State	Red	Food

characters except flag leaf area during the 2010 rainy season at Sokoto (Table 3). Similarly the genotypes exhibited significant (P ≤ 0.05) differences between themselves for all characters except straw weight during 2011 rainy season at Bubuche (Table 4). This indicates that the performance of the genotypes vary across the two environments, which could be due to their varying genotypic origin or as a result of the influence of genotype x environment interaction. It must be noted that, exploitation of genetic variability is an important tool in plant breeding for sorghum hybrids which has to be inferred by phenotypic expression. The consequences of the phenotypic variations depend largely on environmental changes; these variations are further complicated by the fact that all genotypes do not respond similarly to environmental changes (Ghazy.Mona et al., 2012). Mean yield across different environments are adequate indicator of genotypic performance, but only, in the absence of genotype- environment interaction (Mustapha et al., 2001; Yan and Kang, 2003; Ezzat et al., 2010).

Results of the combined analysis across locations showed significant (P ≤ 0.05) differences exists between the varieties for all traits (Table 5). Maarouf and Moataz (2009) reported variation between sorghum genotypes with respect to fodder production. The result was further supported by the genotype x location analysis (Table 6), where genotype by location interaction had significant influence on plant height (6804.4**), leaf area index (0.86*) and flag leaf length (67.99*) (Table 6), which indicate that, simultaneous selection for these traits is not possible across the two environments and that selection for each location have to be carried out separately. This limit their wider utilization, as reported by Pham and Kang

Table 3. performance of Sorghum genotypes evaluated at Usmanu Danfodiyo University Sokoto teaching and research farm during 2010 rainy season

Genotype	LN (cm)	LL(cm)	PH (cm)	LAI (cm^2)	FLA (cm^2)	FLL(cm)	STRW (kg/ha)	100-SWT (g)	TAY (kg/ha)
Zago Ex-Batsari	14.357^{a}	76.793^{ab}	124.84^{b}	0.8667^{ab}	41.433^{a}	32.980^{ab}	5.203^{bc}	4.533^{b}	381.9^{b}
NG/SA/07/005	14.183^{a}	75.533^{ab}	184.60^{a}	2.0333^{a}	45.810^{a}	29.237^{b}	7.693^{ab}	5.867^{ab}	353.^{ab}
NG/SA/07/125	13.130^{a}	80.180^{a}	194.55^{a}	0.7667^{c}	35.970^{a}	29.370^{b}	7.207^{ab}	9.767^{ab}	1154.10^{ab}
NGB/06/001	14.267^{a}	75.733^{a}	183.17^{a}	1.9000^{ab}	46.003^{a}	35.673^{ab}	8.473^{a}	12.667^{ab}	528.5^{ab}
NG/SA/DEC/07/0049	14.690^{a}	79.267^{a}	185.38^{a}	1.2000^{abc}	38.370^{a}	32.233^{ab}	7.493^{ab}	12.067^{ab}	1629.2^{a}
NG/SA/DEC/07/0108	14.707^{a}	74.700^{ab}	190.02^{a}	0.7667^{c}	41.267^{a}	31.087^{ab}	7.170^{ab}	14.863^{a}	400.2^{ab}
NG/SA/DEC/07/0213	12.767^{ab}	78.133^{ab}	171.27^{ab}	1.6833^{abc}	38.727^{a}	34.943^{ab}	7.000^{ab}	8.213^{ab}	419.3^{ab}
NG/SA/DEC/07/0123	13.433^{a}	71.833^{b}	173.94^{ab}	1.6000^{abc}	46.447^{a}	34.883^{ab}	4.233^{c}	8.513^{ab}	280.2^{b}
NG/SA/DEC/07/0036	14.400^{a}	75.500^{ab}	181.90^{a}	1.2000^{abc}	39.367^{a}	33.363^{ab}	7.890^{a}	13.370^{ab}	314.7^{b}
EX-Argungu (Kaura)	10.633^{b}	72.733^{b}	175.93^{ab}	1.2333^{abc}	44.867^{a}	38.633^{a}	3.357^{c}	10.288^{ab}	387.3^{b}

Mean with the same letter(s) in a column are not significantly different at 5% level of significance according to DMRT (Duncan's multiple range tests). LN, leaf number; LL, leaf length in cm; PH, plant height in cm; LAI, leaf area index cm^2; FLA, flag leaf area in cm^2; FLL, flag leaf length in cm; STRW, straw weight in kg; 100-SWT, 100-seed weight in g; TGY, total grain yield in kg/ha.

Table 4. Mean performance of Sorghum genotypes evaluated at Bubuche Augie local government, Kebbi State during 2011 rainy season

Genotype	LN (cm)	LL(cm)	PH (cm)	LAI (cm^2)	FLA (cm^2)	FLL (cm)	STRW (kg/ha)	100-SWT (g)	TAY (kg/ha)
Zago Ex-Batsari	10.33^{ab}	62.567^{abc}	237.60^{ca}	0.7333^{b}	125.13^{ab}	31.067^{abcd}	3.480^{a}	11.417^{abc}	1751^{a}
NG/SA/07/005	13.433^{a}	47.600^{c}	142.51^{bcde}	0.9333^{b}	88.43^{b}	21.967^{d}	3.117^{a}	9.630^{abc}	362^{a}
NG/SA/07/125	8.567.^{ab}	66.067^{ab}	61.73f	0.9333^{b}	207.43^{a}	40.533^{a}	3.073^{a}	16.177^{a}	3374^{a}
NGB/06/001	9.833^{ab}	70.300^{ab}	199.53^{ab}	1.2333^{b}	142.67^{ab}	33.667^{abc}	3.080^{a}	14.560^{ab}	750^{a}
NG/SA/DEC/07/0049	7.900^{b}	79.133^{a}	94.38^{e}f	0.3333^{b}	191.30^{ab}	39.000^{ab}	4.070^{a}	7.370^{bc}	603^{a}
NG/SA/DEC/07/0108	11.833^{ab}	69.667^{ab}	161.88^{bcd}	2.3000^{a}	223.20^{a}	39.000^{ab}	2.630^{a}	8.590^{abc}	425^{a}
NG/SA/DEC/07/0213	12.533^{ab}	68.767^{ab}	186.58^{abc}	.1333^{b}	173.60^{ab}	33.733^{abc}	5.297^{a}	4.417^{c}	370^{a}
NG/SA/DEC/07/0123	9.000^{ab}	61.100^{bc}	133.14^{cde}	0.7333^{b}	123.90^{ab}	30.867^{abcd}	2.355^{a}	10.333^{abc}	336^{a}
NG/SA/DEC/07/0036	11.467^{ab}	60.400^{bc}	133.51^{de}f	0.9667^{b}	142.13^{ab}	28000^{cd}	2.963^{a}	9.037^{abc}	401^{a}
EX-Argungu (Kaura)	11.800^{ab}	52.667^{bc}	162.94^{bcd}	1.2333^{b}	124.60^{ab}	30.500^{cbd}	2.263^{a}	8.297^{abc}	1395^{a}

Mean with the same letter(s) in a column are not significantly different at 5% level of significance according to DMRT; LN, leaf number; LL, leaf length in cm; PH, plant height in cm; LAI, leaf area index cm^2; FLA, flag leaf area in cm^2; FLL, flag leaf length in cm; STRW, straw weight in kg; 100-SWT, 100-seed weight in g; TGY, total grain yield in kg/ha.

(1988) who stated that, significant G x E for a quantitative trait is known to reduce the usefulness of the genotype means over all locations or environments for selecting and advancing superior genotypes to the next stage of selection.

Leaf number (8.68), leaf length (96.44), flag leaf area (3131.93), straw weight (3.8), 100-seed weight (34.68), and total grain yield (1233080) recorded non significant G × E interaction influence (Table 6). Selection for these traits can therefore be done across the locations. Basford and Cooper (1998) reported that, if there are no G x E influence for a character, selection would be greatly simplified because the 'best' genotype in

Table 5. Combined mean performance of Sorghum genotypes evaluated across the locations during 2010 and 2011 rainy seasons.

Genotypes	LN (cm)	LL(cm)	PH (cm)	LAI (cm^2)	FLA(cm^2)	FLL(cm)	STRW(kg/ha)	100-SWT (g)	TAY(kg/ha)
Zago Ex-Batsari	12.345^{ab}	9.680^{bc}	181.22^{ab}	0.8000^{cd}	83.28^{ab}	32.023^{a}	4.3417^{abc}	7.975^{ab}	106.66^{ab}
NG/SA/07/005	13.808^{a}	61.567^{c}	163.56^{abcd}	1.483^{abc}	67.12^{b}	25.602^{b}	5.4050^{a}	7.748^{ab}	358.10^{b}
NG/SA/07/125	10.848^{b}	73.123^{ab}	128.14^{d}	0.8500^{abc}	121.70^{ab}	34.952^{a}	5.1400^{ab}	12.972^{a}	2264.0^{a}
NGB/06/001	12.050^{ab}	73.017^{ab}	191.35^{a}	1.5667^{e}	94.34^{ab}	34.670^{a}	5.7767^{a}	13.613^{a}	639.4^{b}
NG/SA/DEC/07/0049	11.295^{ab}	79.200^{c}	139.88^{cd}	0.7667^{d}	114.84^{ab}	35.983^{a}	5.7817^{a}	9.718^{ab}	1116.2^{ab}
NG/SA/DEC/07/0108	13.270^{ab}	72.183^{ab}	175.95^{abc}	1.533^{ab}	132.23^{a}	35.043^{a}	4.9000^{ab}	11.707^{ab}	472.7^{b}
NG/SA/DEC/07/0213	12.650^{ab}	73.440^{ab}	17.92^{abc}	1.3833^{abcd}	106.16^{ab}	34.338^{a}	6.1483^{a}	6.315^{b}	394.6^{b}
NG/SA/DEC/07/0123	11.217^{ab}	66.467^{ab}	153.54^{abcd}	1.667^{abcd}	85.17^{ab}	32.875^{a}	3.2933^{bc}	9.423^{ab}	808.3^{b}
NG/SA/DEC/07/0036	12.933^{ab}	67.950^{bc}	147.71^{bcd}	1.0833^{abcd}	90.75^{ab}	31.082^{ab}	5.4267^{a}	11.203^{ab}	357.7^{b}
EX-Argungu (Kaura)	10.848^{b}	62.700^{bc}	169.44^{abc}	1.233^{abcd}	84.78^{ab}	34.567^{a}	2.800^{c}	9.290^{ab}	891.3 ^{ab}

Mean with the same letter(s) in a column are not significantly different at 5% level of significance according to DMRT. LN, leaf number; LL, leaf length in cm; PH, plant height in cm; LAI, leaf area index cm^2; FLA, flag leaf area in cm^2; FLL, flag leaf length in cm; STRW, straw weight in kg; 100-SWT, 100-seed weight in g; TGY, total grain yield in kg/ha.

Table 6. Analysis of variance of ten sorghum genotypes evaluated at Sokoto in 2010 and at Bubuche in 2011.

Source of variation	Replication	Environment (E)	Genotype (G)	GXE	Error	CV (%)
LN	1.63	133.8**	6.05	8.68	5.41	19.12
LL	57.96	2236.99**	174.17**	96.44	59.53	11.03
PH	918.04	11081.45**	2447.53*	6804.4**	1151.39	20.82
LAI	0.24	1.07	0.56	0.86*	0.35	49.51
FLA	3736	189551.36**	2440.1	3131.93	2277.29	48.68
FLL	102.82*	0.97	55.45*	67.99*	26.87	15.65
STRAW-WT	1.23	167.27**	7.3*	3.8	2.81	34.2
100-GWT	3.85	0.02	33.32	34.68	28.01	52.93
TGY	2160295.73	2304031.05	2194585.25	1233080	1838198	173.62

** Significant at $p<0.01$, *Significant at $p<0.05$; LN, leaf number; LL, leaf length in cm; PH, plant height in cm; LAI, leaf area index cm^2; FLA, flag leaf area in cm^2; FLL, flag leaf length in cm; STRW, straw weight in kg; 100-SWT, 100-seed weight in g; TGY, total grain yield in kg/ha.

one environment would also be the ‘best’ genotype for all target environments. Therefore, variety trials conducted at only one location is enough to provide universal results (Melkassa Agricultural Research Center, 2007). According to Popspisil et al. (2009) high yield of forage sorghum green mass is possible during the growing season, and the crop’s good adaptation to different agroecological conditions make sorghum a very important forage crop. Even though green mass, dry matter yields and nutritional value of forage sorghum depend on the development stage at which cutting was carried out. Németh and Izsáki (2005) reported that about 70% of total dry matter is produced in the second part of sorghum growing season, namely, from day 59 to 103. This explains the non significant genotype x location interaction effect observed for straw weight.

Conclusion

The study indicates that selection for plant height, leaf area index and flag leaf length, cannot be carried out across the two environments, suggesting that selection for these traits have to be carried separately in each of the two environments. However, selection for leaf number, leaf length, flag leaf area, straw weight, 100-seed weight, and total grain yield can be carried out in either of the two environments and is applicable in the other environment.

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