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By S. H. Mohammed & M. I. Mohammed

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S. H. Mohammed [α] & M. I. Mohammed [σ]

Abstract- Assessing new maize cultivars requires studying both yield and stability performance across the major range of environments. Four trials were conducted in Sudan (Africa) during 2013 – 2014. Nine maize genotypes were investigated for forage yield stability across 8 test-environments created by a combination of 2 levels of location, season and watering regime assumed to impose respective effects of salt, heat and water stresses. Wricke's ecovalence, Eberhart-Russell and AMMI stability models were employed to study yield stability. The genotypes and watering regimes were arranged in RCB design in split-plot experiment. The study revealed maize hybrids having broad and specific responses to the studied environments with most genotypes showing consistent stability performance in the three models. Two of the 3 top-yielding hybrids showed relative stability whereas the third one exhibited specific adaptability to low yielding environments. It was concluded that yield stability could be better investigated if the varieties are purposely subjected to major factors affecting yield in a given domain. Different stability models were recommended to avoid limitations arising from using a single model.

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I. Introduction

Maize (*Zea mays* L.) is one of the World's three most important cereal crops. It is the primary source for coarse-grain representing 55% of the World consumption of animal feed [1]. Although the crop is cultivated in a wide range of environments due to its relatively wide adaptability [2] it is the least tolerant to abiotic stresses among cereals. Drought, salinity and elevated temperatures coupled with low humidity [1] are among the major abiotic stresses that negatively impact maize production.

Identification of high yielding cultivars with wide adaptability is the ultimate aim of plant breeders. However, attaining this goal is complicated by the genotype x environment (GxE) interaction. Therefore, assessing of new cultivars must be based not only on their yielding ability but also on their stability and adaptability across broad range of environments to avoid the misleading results caused by GxE interaction and to identify cultivars having the adaptability to specific environments. Several models could be used to study GxE interaction. The Wricke's ecovalence model [3] simply quantify the contribution of each genotype in GxE interaction as a measure of stability related directly to the non-additive structure. Joint linear regression is another widely used model in plant breeding for analyzing and interpreting GxE interaction and determining yield stability of genotypes. It involves the regression of genotype means on an environmental index [4] and provides means of testing whether the genotypes have characteristic linear responses to environmental change [5]. Additive main effects and multiplicative interaction (AMMI) model is a powerful tool in diagnosing GxE patterns of interaction [6]. It is a multimodal approach that proved useful in understanding complex genotype x environment interactions.

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The objectives of this study were to investigate forage yield stability of maize hybrids subjected to predetermined test-environments reflecting various levels of abiotic stress.

II. Materials and Methods

The experiment was conducted in Khartoum State during 2013-2014 under two seasons (summer and winter) and two locations: Shambat (Lat. 15° 39' N; Long. 32° 31' E; Alt 380 masl) and Soba (Lat.15° 24' N; Long.32° 32' E; Alt 380 masl). In each location the trial was carried out in the Experimental Farm of the Agricultural Research Corporation (ARC).

a) *Soil and climatic conditions*

The soil at Shambat is well-drained loamy clay, non-saline and non-sodic, with pH ranging from 7.71 to 7.91. The soil at Soba is hazarded by salinity (ECe = 12 - 14 dS/m) and sodality (ESP = 24 - 27, SAR = 16 –23) with high clay content, low infiltration and permeability, low organic matter, low nitrogen and high pH. The average min-max temperature during the winter season (Nov. –Feb.) ranged 15-20°C and 32-38°C whereas that at summer (April-July) ranged 25.0-28.4°C and 36.9-42.0 °C. The weather is dry in both growing seasons especially during winter. For further details of soil and climatic conditions see Appendices I through V.

b) *The plant material*

The plant materials used in the study (Table 1) included nine maize genotypes comprising 8 hybrids plus one open-pollinated cultivar. Six of the maize genotypes have already been released for commercial production in Sudan.

Table 1: Plant material used in the study

Genotypes	Type/Color	Source
PAN6966	Yellow maize hybrid	Pannar Co. South Africa
PAN-12	Yellow maize hybrid	Pannar Co. South Africa
PAN-14	Yellow maize hybrid	Pannar Co. South Africa
PAN6P-110	Yellow maize hybrid	Pannar Co. South Africa
Hytech1100	White maize Hybrid	MisrHytech Co. Egypt
Hytech2066	Yellow Maize hybrid	MisrHytech Co. Egypt
Hytech2031	White Maize hybrid	MisrHytech Co. Egypt
Hytech2055	Yellow Maize hybrid	MisrHytech Co. Egypt
Hudieba2	Yellow Maize (open pollinated)	Agric. Res. Corporation (ARC) Sudan

c) Cultural practices

Four trials were conducted in the winter and summer seasons at Shambat and Soba locations. Unless otherwise indicated, the cultural practices followed were the same in the different trials. The land was disc ploughed, disc harrowed and leveled by the scraper to obtain fine seed bed. Ridging was done at 0.75 m spacing. The plot consisted of four ridges 4 m long. Two seeds were placed in holes spaced at 10 cm on one side of the ridge. The winter sowing was on the 8th and 12th of Dec. 2013 in Soba and Shambat, respectively. The summer sowing was on the 13th and 19th of May 2014 in Soba and Shambat, respectively. Nitrogen fertilizer (55 kg N/ha) was applied at growth stage-2 (four leaves completely unfolded). Weed population was controlled by hand weeding.

d) Treatments and the experimental design

The genotypes were subjected to the following main treatments factors in a randomized complete block design (RCBD) with three replications:

- Two watering intervals applied at one and two weeks using split-plot experiment with watering regimes assigned to the main plots and the genotypes to the sub-plots
- Two growing seasons: Summer and winter (normal).
- Two locations: Soba and Shambat.

The combination of location, season and watering regime (2x2x2) provided 8 test-environments (Table 2) assumed to bring about different test environments used to investigate yield stability of the 8 maize genotypes

Table 2: The test-environments

S. No.	Location	Season	Year
1	Soba	Winter	13/2014
2	Shambat	Winter	13/2014
3	Soba	Summer	2014
4	Shambat	Summer	2014
5	Soba	Summer	2017
6	Shambat	Summer	2017
7	Soba	Winter	2017/18
8	Shambat	Winter	2017/18

III. Data Collection and Statistical Analysis

Forage yield was estimated at the milk stage from the two inner rows of each plot leaving 0.5 m from each side of the ridge. The plants were cut at the ground level and weighed immediately using spring balance. Dry matter yield (DMY, t/ha) was estimated from a random sample of 0.5 kg taken from the fresh harvested plants in each plot and air-dried to a constant weight. Days to 50% tasselling, plant height, stem diameter and quality traits (NDF, ADF, CP) were studied but will not be highlighted in this study.

Analysis of variance was performed following the standard procedure of analyzing split plot in RCB design [7]. Combined analysis of variance to assess the magnitude of genotype-environment interaction (GEI) was performed. Then mean squares of GEI was used to test the effect of genotypes. Analysis of yield stability for nine maize genotypes was carried out over the eight environments using the following stability models:

a) Wricke's ecovalence (Wi)

According to this model, the stability of the genotype is its interaction with environments, squared and summed across environments [3]. The formula of this model is as follows:

$$Wi = \sum(Y_{ij} - Y_{.j} - Y_{i} + Y_{...}) \qquad [2]$$

Where: Y_{ij} = Mean of genotype i in environment j, $Y_{.j}$ = Mean yield of genotype across environments, Y_i = environment mean, $Y_{...}$ = Overall mean.

b) Eberhart and Russell Stability Regression Model

The equation underlying this model [5] is as follows:

$$Y_{ij} = m + B_i I_j + \delta_{ij}$$

Where:

i=1, 2,…..g (number of genotypes)

j=1, 2,…...s (number of environment)

Y_{ij}= The mean yield of ith genotype in the jth environment.

m = The mean of all genotypes overall environments

B_i = The regression coefficient of the ith genotype on environment index, which measures the response of this genotype to varying environments.

I_j= The environment index which is defined as the deviation of the mean of all genotypes at a given environment from the overall mean.

δ_{ij} = The deviation from regression of i^{th}genotype at j^{th} environment.

The regression coefficient (bi), was estimated as:

$$bi = j\sum Y_{ij}Ij / \sum I^2 j$$

Where:

bi = regression coefficient of the i^{th} genotype

Y_{ij} =the mean yield of i^{th} genotype in the j^{th} environment.

Ij= environmental index obtained as the mean of all genotypes at the j^{th} environment minus the grand mean.

Deviation from regression ($\sigma^2 d$) suggested by Eberhart and Russel, (1966) estimated as:

$$\sigma^2 d = \sum \delta^2_{ij}/(S\text{-}2)\text{-}Se^2/r,$$

Where:

$\delta^2_{ij} = (\sum Y_{ij} - Yi/g)\text{-}(\sum Y_{ij}\, I^2)$

r = number of replications

g = number of genotypes, and s=number of environment.

Se = the pooled error.

δ_{ij} = the deviation from regression of i^{th} genotype at j^{th} environment.

Y_{ij} =the mean yield of i^{th} genotype in the j^{th} environment.

c) *Additive Main Effects and Multiplication Interaction (AMMI) Stability Model*

The AMMI model equation [8] is:

$$Y_{ij} = \mu + G_i + E_j + \sum_{\kappa=1}^{n} \lambda_\kappa \alpha_{ik} \gamma_{jk} + e_{ij}$$

Where:

Y_{ij} is the yield of the i^{th} genotype in the j^{th} environment;

μ is the grand mean;

G_i and E_j are the genotype and environment deviations from the grand mean, respectively;

λ_κ is the eigen value of the PCA analysis axis ;

κ ; α_{ik} and γ_{jk} are the genotype and environment principal component scores for axis ;

κ ; n is the number of principal components retained in the model

e_{ij} the residual.

The statistical package Agrobase [9] was used to run the three models of stability analysis

IV. Results

Mean squares from combined analysis of variance for forage yield of 9 maize genotypes over the 8 test-environments are presented in Table 3. Differences among environments, genotypes and genotype by environment interaction were highly significant for forage yield.

Table 3: Mean squares from combined ANOVA for forage yield of nine maize genotypes studied over eight environments

Source of variation	DF	Dry matter yield (t/ha)
Environments (E)	7	178.137**
Reps within (E)	16	0.714
Genotypes (G)	8	31.031**
G×E	56	3.293**
Residual	128	0.472

** = Highly significant at 0.01 probability level

a) *Wricke Ecovalence*

Wi-ecovalance stability values and mean performance of nine maize genotypes across eight environments for DMY are presented in Table 4. The genotype Hytech2055 ranked top in forage yield (10.8 t/ha) coupled with the second-lowest stability value (wi = 2.961). PAN12 ranked third in both yield (10.3 t/ha) and stability value (wi = 3.475). PAN14 exhibited the lowest stability value (wi =2.517), coupled with the lowest forage yield (7.75 t/ha). In contrast, Hytech2031 averaged the second-top yield (10.5 t/ha) coupled with the second-highest stability value (wi = 9.850).

Table 4: Stability values (Wi-ecovalance) and mean performance in dry matter yield (DMY) of maize genotype

Genotypes	DMY (t/ha)	Wi-ecovalance†	Variations explained (%)
PAN6966	8.38 (6)	5.253 (5)	8.55
PAN12	10.3 (3)	3.475 (3)	5.65
PAN14	7.75 (9)	2.517 (1)	4.09
PAN6P-110	8.50 (5)	8.739 (7)	14.22
Hytech1100	8.13 (8)	17.531 (9)	28.52
Hytech2066	9.50 (4)	6.961 (6)	11.32
Hytech2031	10.5 (2)	9.850 (8)	16.02
Hytech2055	10.8 (1)	2.961 (2)	4.82
Hudeiba2	8.38 (7)	4.184 (4)	6.81
Grand mean	9.13		

Figures between brackets denote rank

† : Smaller value indicates better yield stability

b) *Eberhart and Russell's Stability Model*

Table 5 shows the ANOVA from Eberhart-Russell Regression Model for forage yield of nine maize genotypes tested across 8 environments. The analysis of variance revealed significant differences among genotypes for forage yield. The GxE (linear) was significant. Table 6 shows the parameters of yield stability for DMY of nine maize genotypes across 8 environments. The genotype Hytech2055 ranked top in forage yield (10.8 t/ha), showed the closest regression coefficient to unity (bi=1.0309) and small deviation from regression (σ^2d=0.320). PAN12 ranked third in forage yield (10.3 t/ha), showed regression coefficient close to unity (bi=1.0736) and small deviation from regression (σ^2d = 0.211). Hytech2031ranked second in forage yield (10.5 t/ha) with regression coefficient well below unity (bi= 0.7993) and exhibited the second largest deviation from regression (σ^2d = 1.165). Hytech2066 showed above average yield, regression coefficient ranking second in closeness to unity and large deviation from regression.

Table 5: ANOVA from Eberthart and Russell's stability model for dry matter yield (t/ha) of nine maize genotypes

Source	DF	MS
Genotypes (G)	8	10.344**
Environment (E).+ in G.x E.	63	7.573
E. in linear	1	0.000
G x E. (linear)	8	1.748*
Pooled deviation	54	0.879
Residual	144	0.166

*, ** = Significant and highly significant at 0.05 and 0.01 probability level, respectively

Table 6: Mean performance and stability parameter of maize genotypes evaluated across eight environments using Eberthart and Russell's stability model

Genotypes	Dry matter yield (t/ha)		Regression coefficient (bi)		Deviation from linearity of regression (σ^2d)	
PAN6966	8.38	(6)	1.1855	(5)	0.521	(5)
PAN12	10.3	(3)	1.0736	(3)	0.211	(2)
PAN14	7.75	(9)	1.1563	(4)	0.266	(3)
PAN6P-110	8.50	(5)	0.7085	(9)	0.636	(6)
Hytech1100	8.13	(8)	1.2724	(8)	2.184	(9)
Hytech2066	9.50	(4)	0.9660	(2)	0.985	(7)
Hytech2031	10.5	(2)	0.7993	(7)	1.165	(8)
Hytech2055	10.8	(1)	1.0309	(1)	0.320	(4)
Hudeiba2	8.38	(7)	0.8075	(6)	0.128	(1)
Grand mean	9.13					

Figures between brackets denote rank

c) AMMI Stability model

The mean squares from AMMI analysis of variance (Table 7) indicated significant variations among the genotypes, the environments and their interaction for forage yield. The GxE is highly significant accounting for 10.53% of the sum of squares. The genotype x environment interaction (GxE) was partitioned into seven interaction principal component analysis axis (IPCA). The IPCA1 and IPCA2 scores are highly significant explaining 51.79% and 22.27% of the variability relating to GxE, respectively (totaling 74.1%). Table 8 shows the IPCA axis scores and forage yield for nine maize genotypes averaged across 8 environments. Hytech-2055, the highest yielding genotype scored the second lowest value in IPCA1 (0.2686) and the lowest value in IPCA2 (0.3191). The genotype PAN12 that ranked third in forage yield scored the lowest value in IPCA1 (-0.0726) coupled with high value in IPCA2 (-0.7807). Hytech2031, the second highest yielding genotype scored the second highest value in IPCA1 (0.9609) and IPCA2 (0.8561).

Table 7: Mean squares from AMMI stability model and the percentage of G x E explained by each IPCA† for dry matter yield (t/ha) of nine maize genotypes grown in eight environments

Source	DF	SS	MS	F-value	Prob.> F	Variations explained (%)
Total	215	1751.472				100
Environments (E)	7	1246.958	178.137 **	249.60	0.0000	71.2
Reps within E	16	11.419	0.714			0.65
Genotypes (G)	8	248.250	31.031 **	9.42	0.0000	14.17
G × E	56	184.417	3.293 **	6.98	0.0000	10.53
IPCA1	14	95.513	6.822	14.45	0.0000	(51.79)
IPCA2	12	41.076	3.423	7.25	0.0000	(22.27)
IPCA3	10	25.605	2.560	5.42	0.0000	(13.88)
IPCA4	8	13.509	1.689	3.58	0.0009	(7.33)
IPCA5	6	6.873	1.145	2.43	0.0296	(3.73)

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IPCA6	4	1.794	0.448	0.95	0.4376	(0.97)
IPCA7	2	0.048	0.024	0.03	0.9502	(0.03)
Residual	128	60.427	0.472			3.45

†: IPCA = Interaction principal component analysis axis.
Figures between brackets denote percentage explained by IPCAs from that explained by GxE (10.53)
** = Highly significant at 0.01 probability level

Table 8: IPCA† scores and mean performance in dry matter yield (DMY) of nine maize genotype

Genotypes	DMY (t/ha)		IPCA1		IPCA2
PAN6966	8.38	(6)	-0.4460	(4)	-0.9833
PAN12	10.3	(3)	-0.0726	(1)	-0.7807
PAN14	7.75	(9)	0.3278	(3)	-0.5303
PAN6P-110	8.50	(5)	0.8789	(7)	-0.4147
Hytech1100	8.13	(8)	-1.6497	(9)	0.5641
Hytech2066	9.50	(4)	-0.7686	(6)	0.3310
Hytech2031	10.5	(2)	0.9609	(8)	0.8561
Hytech2055	10.8	(1)	0.2686	(2)	0.3191
Hudeiba2	8.38	(7)	0.5007	(5)	0.6388
Grand mean	9.13				

†: IPCA = Interaction principal component analysis axis
Figures between brackets denote rank

d) *Comparison of yield stability ranking in the different models*

Table 9 shows forage yield and stability ranking in 3 stability models for nine maize genotypes. As could be noticed in this table there were no major changes in stability ranking for the 9 maize genotypes across the 3 stability model. Hudieba2 might be one of the exceptions ranking first in Eberhart and Russel's model, fourth and fifth in Ecovalance and AMMI models, respectively. PAN12, the third-highest yielding genotype averaged the lowest rank across the 3 stability models. Hytech2055, the highest yielding genotype ranked third in average stability ranking. Hytech2031, the second-highest yielding genotype averaged the second highest stability rank across the 3 models.

Table 9: Dry matter yield (DMY) and average stability ranking of maize genotypes tested across eight environments

Genotypes	DMY(t/ha)		Wricke (wi)-ecovalance		Eberhart & Russel's (deviation σ^2d)		AMMI (IPCA1) scores		Average stability rank
PAN6966	8.38	(6)	5.253	(5)	0.521	(5)	-0.4460	(4)	4.7
PAN12	10.3	(3)	3.475	(3)	0.211	(2)	-0.0726	(1)	2
PAN14	7.75	(9)	2.517	(1)	0.266	(3)	0.3278	(3)	2.3
PAN6P-110	8.50	(5)	8.739	(7)	0.636	(6)	0.8789	(7)	6.7
Hytech1100	8.13	(8)	17.531	(9)	2.184	(9)	-1.6497	(9)	9
Hytech2066	9.50	(4)	6.961	(6)	0.985	(7)	-0.7686	(6)	6.3
Hytech2031	10.5	(2)	9.850	(8)	1.165	(8)	0.9609	(8)	8
Hytech2055	10.8	(1)	2.961	(2)	0.320	(4)	0.2686	(2)	2.7
Hudeiba2	8.38	(7)	4.184	(4)	0.128	(1)	0.5007	(5)	3.3
Grand mean	9.13								

Figures between brackets denote rank

V. Discussion

The highly significant genotype x environment interaction (GxE) validates the performing of stability analysis to know the contribution of each genotype to GxE which is the basic cause for differences between genotypes in their yield stability [10]. In the present study, the maize genotypes were studied under eight environment representing stress conditions resulting from the main effects of heat, salt, water and their interactions. Thus, the assessment of genotypes for yield stability should be considered within the context of the studied environments. We think that the test environments used in this study are appropriate since maize was evaluated as a forage crop assumed to have less demands of input and capable to flourish under marginal environments.

No one biometrical model can adequately explain the stability performance of genotype across environment [11]. In this study, three models with different statistical approaches were used to avoid limitations arising from using a single model. In Wricke's Ecovalence model the cultivars with the lowest value contributed the least to the GxE interaction and are therefore more stable. Based on yield level and Ecovalence value the hybrid Hytech2055 can be regarded as the most stable as it ranked top in forage yield with the second lowest Ecovalence value. Similar conclusions were reported regarding the grain yield stability of the hybrid Hytech2055 [12]. The hybrid PAN12 came second in yield stability ranking third in forage yield coupled with the third lowest Ecovalence value. Hytech2031, though ranked the second top in forage yield failed to demonstrate good yield stability showing the second largest Ecovalence value.

In Eberhart and Russell model [5], two statistics were employed, namely: the regression coefficient as a measure of response [4] and deviation from linearity of regression [5] as stability measure. Results based on this model and similar techniques may be misleading if the genotype response over environment is not linear [6]. However, in this study the linearity of GxE is highly significant, validating the results obtained from Eberhart and Russell's model. Mean yield of entries across all environments and regression coefficients are important indicators of cultivar adaptation [4]. A regression coefficient approximating 1.0 indicated average stability, and in association with high yield, the entry possesses general adaptability. However, entries with a low yield would be poorly adapted to the environment. Regression coefficient values increasing above 1.0 describe genotypes with increasing sensitivity to environmental change, thus below average stability. Regression coefficients decreasing below 1.0 provide a measure of greater resistance to environmental change, thus above average stability. However, regression coefficients must also be associated and interpreted with genotype mean yields to determine adaptability. In addition to the regression coefficient, Eberhart and Russell [5] added deviation from the regression as a measure of stability, where an entry would be considered stable with a deviation close to zero. Thus, based on the results of this study, the hybrid Hytech2055 exhibited the best general adaptability ranking top in forage yield with the least regression coefficient value. It showed moderate stability value ranking fourth in the deviation from the linearity of regression. The hybrids PAN12 and Hytech2066 came second in general adaptability, however, the former showed good stability parameter ranking the second-lowest in the deviation from linearity. The hybrid Hytech2031 though ranking second in forage yield, however, its regression coefficient value was well below unity suggesting greater resistance to environmental change, and therefore increasing specificity of adaptability to low-yielding environments. This was in conformity with the best yield obtained by this hybrid under full stress level. Therefore, Hytech2031 could have the relative advantage over the studied cultivars for forage production under the salt affected areas. Similar conclusions were reported for the adaptability of the hybrid Hytech2031to low-yielding environments [12].

The Additive Main effects and Multiplicative Interaction method (AMMI) employs the ANOVA procedure and Principle Component Analysis (PCA) to extract a new set of coordinate axes (IPCA) which account more effectively for the interaction patterns [13]. The more the IPCA scores approximate zero, the more stable the genotype is overall the environments sampled. Using PCA, the GxE was decomposed into 7 IPCAs two of them (IPCA1 and IPCA2) explained 74% of GxE variations into pattern-rich model. The variability relating to IPCA3 through IPCA5, though significant was small, therefore regarded as part of the residual. Based on the first two IPCAs, the hybrid Hytech2055 exhibited the best stability score followed by PAN12. The high yielding hybrid Hytech2031showed considerably high scores in both IPCAs pointing to its adaptability to specific environments. As previously discussed Hytech2031 showed specific adaptation to the low yielding environment based on the Eberhart and Russell's stability model. In fact, AMMI model is more powerful in detecting the environments to which genotypes are adapted by employing Biplot analysis [6], However, this feature of AMMI analysis was not used in this study.

The study revealed that there were no major differences between the results obtained from the stability models used in this study. The average rank of genotypes based on the 3 stability models was more or less similar to that obtained for each model. Such conformity gives more reliability to the results obtained.

VI. Summary and Conclusion

The study revealed maize hybrids having broad and specific responses to the studied environments. Yield stability could be better investigated if the varieties are purposely subjected to major factors known to affect yield in a given domain. We recommend using different stability models to avoid limitations arising from using a single model.

Conflict of Interest

The authors declare that there is no conflict of interest.

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Appendix I: Chemical and physical soil properties of the experimental site at Shambat

Depth (cm)	Chemical properties				Physical properties		
	pH	EC (dS/m)	Na (mmol+l)	SAR	Clay (%)	Silt (%)	Sand (%)
0-15	7.79	1.4	5.1	2.4	42.1	15.9	42.0
15-35	7.88	1.0	4.3	2.5	39.6	15.8	44.6
35-51	7.87	1.2	7.1	4.5	44.1	16.4	39.5
51-75	7.91	2. 0	12.5	6.3	51.4	16.6	32.0
75-120	7.71	2.2	16.0	9.2	50.0	16.6	33.4

Appendix II: Chemical soil properties of the experimental site at Soba

Depth	pH paste	pH 1:5	EC dS/m	SAR	ESP
0 - 30	8.1	8.8	14.0	23.0	27.0
30 - 60	8.3	8.9	12.0	16.0	24.0

Soluble Cations and Anions Saturation Extract (meq/L)

	Na	Ca	Mg	Cl	CaCo3	HCo3
0 - 30	10.3	32.5	6.0	8.3	0.0	4.6
30 - 60	19.0	32.5	6.5	6.3	0.0	4.3

Exchangeable Bases (Meq/100g)

	Na	K	CEC	N(%)	C/N%	Available P (ppm)
0 - 30	10.94	0.94	40	0.421	0.037	5.0
30 - 60	6.83	1.04	28	0.468	0.042	3.8

Source: Soil survey and land evaluation report. Land and Water Research Centre.ARC. Wad Medani. Sudan.

Appendix III: Physical soil properties of the experimental site at Soba

Depth (cm)	Mechanical analysis				Soil moisture				H_2o (Cm/cm)	
	Cs	Fs	Si	C	½ bar	15 bar	AWC	Vol%	Soil	Horizon
0 -20	8	18	37	37	27.2	13.6	13.6	22.0	0.33	6.6
20-50	4	30	21	45	28.9	15.5	13.4	21.8	0.22	6.6
50-80	7	17	33	43	28.5	15.3	13.2	22.8	0.23	6.9
80-120	4	23	33	40	27.1	14.6	12.5	20.8	0.21	8.4
120-160	5	20	29	46	36.1	19.0	17.1	30.4	0.30	12.0

Source: Soil survey and land evaluation report. Land and Water Research Centre.ARC. Wad Medani. Sudan.

Appendix IV: Monthly mean temperature (°C), rainfall and relative humidity (R.H %) during the winter season (2013/ 2014).

Month	Mean Temperature		R.H. (%)	Total rain fall (mm)
	Max.	Min.		
November 2013	34.0	20.0	27	0.0
December	32.0	16.0	32	0.0
January 2014	32.0	15.0	35	0.0
February	33.0	16.0	27	0.0
March	38.0	20.0	23	0.0

Source: Meteorological Authority, Ministry of environment Forestry and Physical Development (2014) Khartoum. Sudan.

Appendix V: Monthly mean temperature (°C), rainfall and relative humidity (R.H %) during the summer season (2014).

Month	Mean Temperature		R.H. (%)	Total rain fall (mm)
	Max.	Min.		
April	40.9	27.4	16	Trace
May	41.0	28.4	17	4.6
June	42.0	25.0	21	0.6
July	36.9	26.1	45	73.6

Source: Meteorological Authority, Ministry of environment Forestry and Physical Development (2014) Khartoum. Sudan.