

Full Length Research Paper

## Grain Yield Stability and Adaptability of Some Rice (*Oryza Sativa* L.) Germplasm Materials within the Guinea and Sudan Savannah Zones of Ghana

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Accepted 26th April, 2015.

*Multi-location rice evaluation trials were conducted during the 2013 cropping season at four locations which were key rice production areas within the Guinea and Sudan savannah agro-ecological zones of northern Ghana. Two growing ecologies: one irrigated and one rain-fed were involved in each agro-ecological zone. The purpose of the trials was to evaluate some thirty germplasm materials for grain yield stability and adaptability within the northern savannas. Entries were planted in a randomized complete block design replicated three times in each location. Adaptability studies using Additive Main effect and Multiplicative Interaction (AMMI) analysis for grain yield indicated that the genotype (G), environment (E) and their interaction (GEI) effects were significantly different ( $p < 0.01$ ), indicating broad range of diversity existed among the genotypes. Five genotypes, including Anyofula, Basmati 123, GH1837, Good and New and Perfume (ST) showed superior grain yield performance over the checked material, GR 18, and appeared to be specifically adapted to the higher yielding irrigated sites. On the other hand, genotypes that were identified as broadly adapted to all the four locations included Sebota 87, Matigey, Basmati 113, Sebota 68, IR 72 (pH) and Sebota 36. The adapted materials, especially those which outperformed the checked material, had the potential to increase rice productivity within the northern savannas and were therefore recommended for further breeding work and subsequent release to rice farmers.*

**Keywords:** Germplasm materials, grain yield stability, adaptability, lowland and genotype.

## INTRODUCTION

Rice (*Oryza sativa* L.) is an important grain crop worldwide and is a primary food source for many people. More than half of the world's population depends on rice for its major daily source of food energy and protein and thus the importance of rice in relation to food security and socio-economic stability is self-evident (FAO, 2003). It is the second most important staple food in Ghana and its consumption keeps increasing as a result of population growth, urbanization and changes in consumer eating habits. Its consumption, however, is significantly greater than domestic production, necessitating increased imports that drain huge amounts of scarce foreign exchange (Bam et al., 1998). Average annual rice consumption per capita in Ghana increased from 7.3 kg in 1980s to 22 kg in 2003 when a total of 500,000 tons of rice was imported (ISSER, 2002).

To achieve food security and foreign exchange savings, increased production of highly competitive domestic rice should be the utmost priority of Ghana's agriculture. Even though northern Ghana is a potential breadbasket of the country because of its high production potential for staple food crops- such as rice, maize, sorghum pearl millet and yam- and the largest rural farming population, the region generally experiences hot, distinct, dry and wet conditions. It is also a region with a wide range of agro-ecological and climatic factors with rainfall being extremely variable and erratic. Northern Ghana is, thus, characterized by diverse climatic conditions and soil types which escalate the problem of genotype x environment interaction (GEI). To overcome this problem, the universal practice of scientists in most crops when selecting genotypes, is to plant them in yield (performance) trials over several environments to ensure that the selected genotypes have a high

and stable performance over a wide range of environments. A genotype, which shows a relatively constant yield, independent of environmental condition is characterized as being stable. Therefore the growing of a crop in a particular agro-ecological niche and screening for a stable and adaptable trait will establish a long period of very little change and hence could be selected for farmers

Multi-location trials were therefore conducted in the major rice producing areas of Guinea and Sudan savannah agro-ecological zones of northern Ghana to evaluate some thirty germplasm materials for grain yield stability and adaptability. The specific objectives of the study were to;

1. Evaluate the presence of genotype by environment interactions (GEIs) in the germplasm materials so as to determine their grain yield potential and other agronomic performance within the northern savannas.
2. Determine the most stable and adaptable materials for recommendation to rice farmers within the northern savannas

## MATERIALS AND METHODS

### Experimental sites, treatments and design

Multi-location field trials were conducted at four major rice growing locations of the Guinea and Sudan savannah agro-ecological zones during 2013 major season involving two rainfed and two irrigated lowland ecologies. The sites were Largbani (rainfed) and Libga (irrigated) in the Guinea savannah as well as Nyangua (rainfed) and Tono (irrigated) in the Sudan savannah zones. The names and sources of the materials are indicated in Table 1.

**Table 1: Names and sources of germplasm materials used for the 2013 experiments in the Guinea and Sudan Savannah zones of Ghana**

Name	Source	Name	Source
Sebota 33	Cameroun	IR 72	IRRI, Philippines
Sebota 70	Cameroun	Sebota 69	Cameroun
Sebota 337 -1	Cameroun	Sebota 68	Cameroun
Perfume (ST)	Thailand	Sebota 147	Cameroun
Sebota 330	Cameroun	GH1837	CSIR -PGRI, GH
Sebota 41	Cameroun	Matige y	CSIR -PGRI, GH
Sebota 36	Cameroun	Kawawa Red.	CSIR -PGRI, GH
Sebota 1	Cameroun	Basmati 122	IRRI, Philippines
Sebota 48	Cameroun	GR 18	CSIR -SARI, GH
Local Red	Farmer coll .	Local Basmati 2	IRRI, Philippines
Anyofula	CSIR -PGRI,	Koshihikar i	Japan
Sebota 87	Cameroun	Basmati 113	IRRI, Philippines
Basmati 123	CSIR -PGRI,	Sebota 63	Cameroun
Good and New	Japan	Viwornor	CSIR -PGRI, GH
Basmati 370 -1	IRRI, Philipp	Sebota 281 -2	Cameroun

Thirty rice germplasm materials, including a locally released standard check (GR18) were laid out in a Randomized Complete Block (RCB) design with three replications per trial at each location. Plots were 5m long and 3m wide

#### **Crop establishment and management practices.**

The rain-fed experimental fields were ploughed, harrowed and levelled, while irrigated fields were rotovated and levelled. The seeds for rainfed fields were planted at stake in rows at the recommended population density (20cm x 20cm, three seeds per stand). Seeds were placed in approximately 3–5 cm deep holes made with a dibble stick. Seeds for irrigated fields were nursed and the resulting seedlings transplanted (3 weeks old) into well banded plots of 5mx3m sizes. Population density similar to that of the rainfed sites was maintained in the irrigated fields. The recommended fertilizer application rate of 60-60-30 NPK kg/ha was adopted for the trials with the N component applied in split dose. All other cultural practices were carried out as and when it was necessary.

#### **Data collection**

For each of the locations, soil chemical analyses of the trial sites within the 0-20cm depth was carried out prior to planting. Soil samples were collected, air-dried in the laboratory, ground and sieved through a 2mm sieve. Soil pH was measured using the pH meter in 1:1 soil to water ratio. Macro-nutrients, including nitrogen, phosphorus and potassium were analysed. Percentage total nitrogen was determined by the micro Kjeldahl-technique (Jackson, 1962). The available phosphorus was extracted by the Bray method and determined colorimetrically (Bray and Kurtz 1945). Potassium was determined by flame emission photometry. A guide to the interpretation of soil analytical data by Prof. E. Y. Safo, of Kwame Nkrumah University of Science and Technology (KNUST), Kumasi were used to interpret the data (personal communication) (Appendix 1). Data were taken on the number of tillers per hill 3 and 6 weeks after planting (or sowing), days to 50% flowering, plant height at

maturity, days to maturity, number of panicles per hill, panicle weight, grain length, 1000 grain weight, straw yield and grain yield which were the major character measured for the analysis.

#### **Data collection and analysis**

Data collected were subjected to analysis of variance (ANOVA) to establish treatment and the interaction effect on grain yield and growth characteristics of the materials. All statistical analyses were conducted using the GenStat Statistical program (GenStat 12th Edition). The analysis of variance procedure for multifactor experiments was followed to determine whether differences existed among treatments. All treatment means were compared using the Least Significant Difference (LSD) at 5% level of significance. The effects of the genotypes, environments (locations) and their interactions were determined from the ANOVA analysis. Main effects and all interactions were considered significant when  $P \leq 0.05$ . To assess the effects of genotype, location and genotype x location interaction for each ecology, the data were pooled and analyzed as 30 genotypes x 2 locations so as to estimate the extent of genotype x location interaction effect on the genotypes.

## **RESULTS AND DISCUSSION**

### **Responses of grain yield and other agronomic traits to environments (locations)**

#### **Grain yield**

There were wide differences in the frequency and intensity of rainfall as well as the various soil attributes observed across the four locations within the period under study (Tables 2 and 3) which were characteristic of the Guinea and Sudan savannah zones (Padi, 2007). Thus, the environmental variability across the locations could be responsible for the varied grain yield of the genotypes evaluated during the study period. For grain yield at each location, the contributions of the genotypes to the total source of variation were highly significant ( $P < 0.01$ ) indicating optimal grain yield potential of the genotypes irrespective of the prevailing environmental variability.

Table 2: Rainfall (mm) at Tono, Libga, Nyangua and Largbani in 2013 cropping season

Month	Tono	Libga	Nyangua	Largbani
January	-	-	-	-
February	-	-	-	-
March	-	-	-	-
April	-	-	-	-
May	-	81.17	-	72.24
June	96.21	72.00	105.83	64.08
July	498.58	100.57	448.72	360.00
August	222.00	200.61	216.00	103.00
September	40.00	187.26	102.00	246.00
October	45.39	260.00	35.00	67.00
November	-	9.52	-	6.00
December				
Total rainfall	902.18	911.12	907.55	918.32
Number of rainy days	79	93	59	88

Source: SARI, Manga

Table 3: Range (and mean) of various chemical attributes of the soils at sample points in the trial sites within the 0-20cm depth during the 2013 cropping season in northern Ghana

Soil ariable	Tono	Libga	Nyangua	Largbani
Nitrogen (%)	0.030 – 0.040 (0.034)	0.021 – .030 (0.023)	0.033-0.040 (0.035)	0.050 – 0.64 (0.056)
Phosphorus (mg/kg)	4.00 – 4.52 (4.26)	3.02 – 4.90 (3.50)	5.03 – 5.28 (5.10)	4.23 – 6.9 (5.84)
Potassium (mg/kg)	64.0 – 70.0 (68.4)	9.0 – 20.0 (14.0)	39.0 – 48.0 (44.6)	24.0 – 55.0 (48.1)
pH	5.2 – 5.8 (5.50)	4.7 – 5.80 (5.25)	5.10 – 5.20 (5.15)	5.13 – 5.70 (5.60)

Minimum, mean and maximum paddy (grain) yields (t/ha) of the 30 rice germplasm evaluated at 4 sites during the 2013 cropping season are presented in Figure 1. As expected, the irrigated sites accounted for the greatest yields, with Tono

producing the greatest maximum and mean yields of 5.37 and 4.06 t/ha respectively. Nyangua and Largbani sites were almost at par in terms of minimum yields and more so with regards to the mean paddy yields.

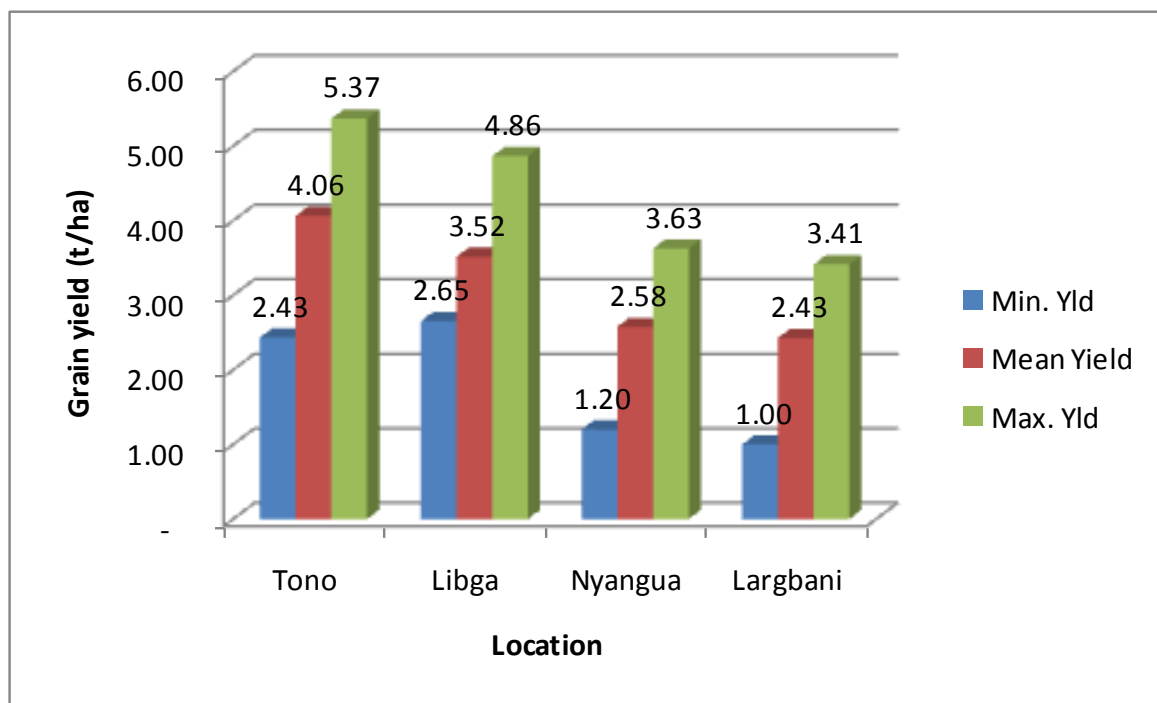


Figure 1: Minimum, mean and maximum grain yields (t/ha) at 14% moisture content (MC) of 30 rice germplasm evaluated at 4 sites during the 2013 cropping season in northern Ghana

Paddy yields of 30 germplasm materials evaluated at the two production ecologies (four locations) during the season are presented in Figures 2 and 3. Consistently, paddy yield of the genotypes at the Tono site, except for IR 72 (Ph), Kawawa Red, Koshihikari, Sebota 41, Sebota 49

and Viwornor, clearly outperformed their counterparts at the Libga site. Inconsistency in paddy yields of the genotypes was more pronounced at the rainfed sites than at the irrigated sites (Figure 3).

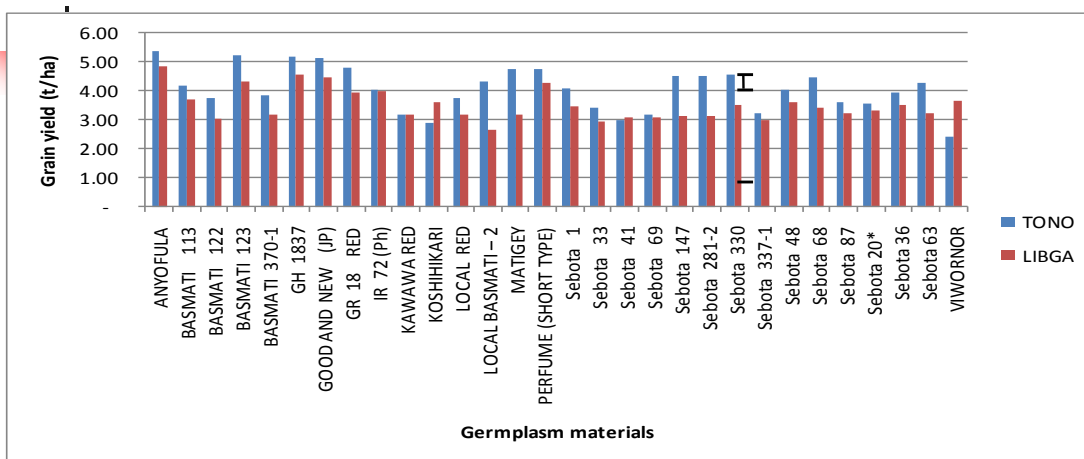
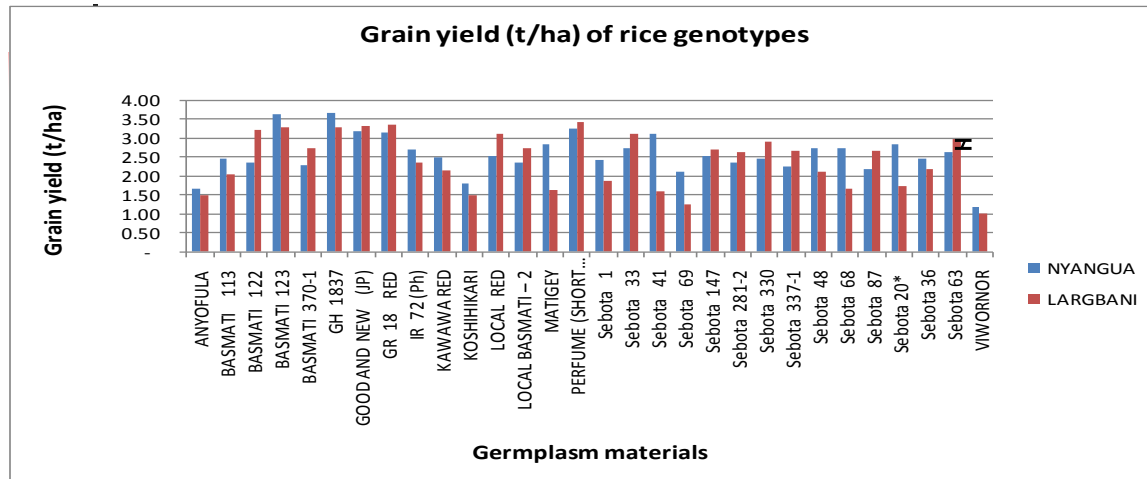


Figure 2: Grain yield of 30 germplasm evaluated at two irrigated sites during the 2013 cropping season



15

Figure 3: Grain yield of 30 germplasm evaluated at two rainfed sites during the 2013 cropping season

In general, there were significant genotypic differences for grain yield at each of the four locations. Consistently, and at each location, five-six genotypes were among the highest yielding genotypes, performing above their respective means. These genotypes included Anyofula, Basmati 123, GR1837, Good and New, GR18 and Perfume (ST) (Table 4). On the other hand, genotypes with lower yields in at least three out of the four locations included Sebota 33, Sebota 337-1, Basmati 370-1, Basmati 122 and Local Basmati-2. Consistently, Matigey, Basmati 113, IR72 (Ph), Sebota 36, Sebota 68 and Sebota 87 maintained yields not significantly different from their respective mean yields across the four locations. At all locations, differences in yield were more pronounced under rainfed sites compared to irrigated sites and as expected, the entries generally maintained consistent grain yield superiority across irrigated sites over the rainfed sites. In terms of grain yield, Tono was the most productive location (mean of 4.06t/ha)

while Largbani the least productive (mean of 2.43t/ha). Yields recorded under rainfed conditions generally recorded higher coefficients of variation compared to yield measurements under irrigated condition.

Table 4: Mean grain yield (t/ha) at 14% moisture content (MC) of 30 rice germplasm materials evaluated under rainfed and irrigated conditions at in four locations during the 2013 cropping season in Northern Ghana.

GENOTYPE	TONO	Locations		
		LIBGA	NYANGUA	LARGBANI
ANYOFULA	5.37	4.86	1.67	1.50
BASMATI 113	4.17	3.70	2.46	2.03
BASMATI 122	3.75	3.03	2.38	3.22
BASMATI 123	5.25	4.32	3.63	3.30
BASMATI 370-1	3.83	3.19	2.29	2.75
GH 1837	5.20	4.58	3.68	3.30
Good & New	5.13	4.47	3.19	3.34
GR 18 RED	4.81	3.96	3.15	3.37
IR 72 (Ph)	4.04	3.98	2.71	2.36
KAWAWA RED	3.17	3.17	2.50	2.17
KOSHIHIKARI	2.90	3.60	1.80	1.50
Loc. Basmati-2	4.33	2.65	2.54	3.10
LOCAL RED	3.75	3.20	2.38	2.73
MATIGEY	4.75	3.17	2.83	1.65
PERFUME (ST)	4.75	4.27	3.25	3.41
Sebota 1	4.08	3.47	2.42	1.87
Sebota 147	4.50	3.15	2.75	3.13
Sebota 20*	3.57	3.30	3.13	1.58
Sebota 281-2	4.50	3.13	2.13	1.25
Sebota 33	3.42	2.93	2.53	2.70
Sebota 330	4.58	3.53	2.37	2.65
Sebota 337-1	3.21	2.98	2.45	2.91
Sebota 36	3.92	3.53	2.25	2.66
Sebota 41	3.00	3.07	2.73	2.10
Sebota 48	4.03	3.62	2.75	1.67
Sebota 63	4.25	3.24	2.20	2.68
Sebota 68	4.46	3.42	2.83	1.75
Sebota 69	3.17	3.07	2.46	2.18
Sebota 87	3.63	3.23	2.63	2.97
VIWORNOR	2.43	3.67	1.20	1.00
Mean	<b>4.06</b>	<b>3.52</b>	<b>2.58</b>	<b>2.43</b>
CV(%)	<b>3.00</b>	<b>2.1</b>	<b>33</b>	<b>23</b>
Lsd (5%)	<b>1.29</b>	<b>0.7</b>	<b>0.6</b>	<b>0.9</b>

Differences in yield were less pronounced under irrigated conditions compared to rainfed conditions which also recorded higher values of coefficients of variation. This observation could be an indication of higher error to genotypic

variance under rainfed relative to irrigated conditions.

Genotypes that maintained consistent grain yield superiority across the four locations were

Anyofula, Basmati 123, GH1837, GR 18, Good and New and Perfume (ST) and could therefore be described as adapted materials. Similarly, Matigey, Basmati 113, IR72 (Ph), Sebota 36, Sebota 68 and Sebota 87 maintained yields not significantly different from their respective mean yields across the four locations, an indication of adaptation to the four environments

#### Genotype x environment interaction

The combined analyses of variance (ANOVA) of the 30 entries evaluated across the four locations

are presented in Tables 5 and 6. The ANOVA indicated highly significant differences ( $P < 0.01$ ) for environments (locations) and genotypes for the irrigated sites (Table 5). The proportion of total sources of variation attributable to the genotypes was highest (43.67%) followed by other factors under error (33.46%) while blocks contributed least to the variation (0.84%). Genotype x Location interaction effect was not significant statistically.

Table 5: Combined analysis of variance with the proportions of the total variance attributable to the sources of variation in grain yield of 30 rice germplasm materials evaluated at two irrigated sites in Ghana during the 2013 cropping season

Source of variation	DF	MS	%SS
Block	2	0.5698	0.84
Genotype	29	2.0352**	43.67
Location	1	13.5773**	10.05
Genotype x location	29	0.5584	11.98
Error	118	0.3832	33.46
Total	179		100
cv%	2.6		

\*\* $P < 0.01$

From Table 6, significant differences ( $P < 0.05$ ) were observed in terms of grain yield performance for environments and highly significant differences ( $P < 0.01$ ) for main effect of genotypes as well as for the interaction of the genotype and the environment under the rainfed

condition. The proportion of total sources of variation attributable to the genotypes was highest (44.24%) followed by other factors under error (33.90%) while blocks contributed least to the variation (0.65%).

Table 6: Combined analysis of variance with the proportions of the total variance attributable to the sources of variation for grain yield of 30 rice germplasm materials evaluated at two rainfed sites in Ghana during the 2013 cropping season

Source of variation	DF	MS	%SS
Block	2	0.2530	0.65
Genotype	29	1.1990**	44.24
Location	1	1.0282*	1.31
Genotype x location	29	0.5393**	19.90
Error	118	0.2258	33.90
Total	179		100
cv%	2.3		

\* $P < 0.05$ ; \*\* $P < 0.01$

#### Other agronomic traits

##### Days to 50% flowering (DFF)

Table 7 presents mean days to 50% flowering of rice germplasm materials evaluated during the 2013 cropping season. The differences among genotypes were significant ( $P < 0.05$ ) for this trait. Kawawa red, Local Basmati 2, Sebota 41, Sebota 63 and Sebota 337-1 were among the earliest to flower across locations. They were, however, not among the best performing

materials in terms of grain yield. At all locations, there was the tendency for materials to flower earlier under rainfed than the irrigated conditions. For some late flowering genotypes, including Anyofula, Koshihikari and Viwornor, flowering was further delayed under rainfed condition leading to poor grain yield for these genotypes (Figure 3).



Table 7: Mean days to 50% flowering of rice germplasm materials evaluated

<b>GENOTYPE</b>	<b>TONO</b>	<b>LIBGA</b>	<b>NYANGUA</b>	<b>LARGBANI</b>
ANYOFULA	133.67	135.67	137.67	136.67
BASMATI 113	73.00	75.00	70.00	71.00
BASMATI 122	72.00	74.00	69.00	70.00
BASMATI 123	70.33	72.33	67.33	68.33
BASMATI 370-1	69.00	71.00	66.00	67.00
GH 1837	68.00	70.00	65.00	66.00
Good & New	46.00	48.00	43.00	44.00
GR 18 RED	92.00	94.00	89.00	90.00
IR 72 (Ph)	97.67	99.67	94.67	95.67
KAWAWA RED	62.67	64.67	59.67	60.67
KOSHIHIKARI	121.33	120.33	126.33	128.33
Loc. Basmati-2	33.33	35.33	30.33	31.33
LOCAL RED	73.00	75.00	70.00	71.00
MATIGEY	125.67	127.67	122.67	123.67
PERFUME (ST)	99.33	101.33	96.33	97.33
Sebota 1	79.67	81.67	76.67	77.67
Sebota 147	79.00	81.00	76.00	77.00
Sebota 20*	79.33	81.33	76.33	77.33
Sebota 281-2	86.00	88.00	83.00	84.00
Sebota 33	77.67	79.67	74.67	75.67
Sebota 330	88.00	90.00	85.00	86.00
Sebota 337-1	60.00	62.00	57.00	58.00
Sebota 36	91.00	93.00	88.00	89.00
Sebota 41	64.00	66.00	61.00	62.00
Sebota 48	88.33	90.33	85.33	86.33
Sebota 63	53.00	55.00	50.00	51.00
Sebota 68	82.67	84.67	79.67	80.67
Sebota 69	94.00	96.00	91.00	92.00
Sebota 87	91.67	93.67	88.67	89.67
VIWORNOR	132.00	131.00	136.00	137.00
<b>Mean</b>	<b>82.78</b>	<b>84.58</b>	<b>80.14</b>	<b>81.14</b>
<b>CV(%)</b>	<b>5.00</b>	<b>8.2</b>	<b>32</b>	<b>21.60</b>
<b>Lsd (5%)</b>	<b>30.00</b>	<b>28</b>	<b>27</b>	<b>23.00</b>

Kawawa red, Local Basmati 2, Sebota 41, Sebota 63 and Sebota 337-1 were among the earliest to flower across locations and yet not among the best in terms of grain yield under rainfed condition. The observation could be a result of stress factors such as drought limiting growth and development of the crop. At all locations, there was the tendency for of materials to flower earlier under rainfed than the irrigated

conditions. This could be a result of physiological mechanisms of the rice crop to escape terminal drought.

Significant genotypic differences were noted among the entries for a number of days to maturity (DM) with a vast majority of the materials having shorter maturity periods relative to their respective mean values. The short maturity period possessed by these is a desirable

agronomic attribute as it enables these genotypes to fit into the short cropping season and erratic rainfall patterns typical of the Guinea and Sudan Savanna zones of Ghana (Padi, 2007).

#### **Panicle weight (PAN Wt) and number of days to maturity (DM)**

The results of panicle weight (PAN. Wt) per hill after harvest and the number of days to maturity (DM) of the entries at the four locations are presented in Table 8. There were significant genotypic variations across the four locations for these traits. The data showed that panicle weight was generally reduced considerably under rainfed conditions compared to those under irrigated conditions. Here again, Anyofula, Basmati 123, GR 18, Good and New, GH1837 and Perfume (ST) were among entries with the greatest panicle weights. The least grain yielding

genotypes such as Sebota 33, Sebota 337-1, Basmati 370-1, Local Basmati-2 and Basmati 122 produced relatively less weights especially under rainfed conditions.

Generally, the irrigated sites recorded greater DM compared to the rainfed sites with Tono recording the greatest mean DM of 121.09 whilst Largbani accounted for the least mean DM of 106.74. A vast majority of the entries, except Good and New and Local Basmati-2, had DM values not significantly lower than the mean DM across locations.

Table 8: Panicle weight (PAN Wt) and number of days to maturity (DM) of rice germplasm materials at four locations under irrigated or rainfed condition in Northern Ghana during the 2013 cropping season

GENOTYPE	TONO		LIBGA		NYANGUA		LARGBANI	
	PAN. Wt(g)	DM	PAN. Wt(g)	DM	PAN. Wt(g)	DM	PAN. Wt(g)	DM
ANYOFULA	4.45	183.70	4.37	180.40	3.35	167.00	3.05	162.36
BASMATI 113	2.39	120.27	2.31	116.97	2.12	109.33	1.61	105.27
BASMATI 122	2.34	107.07	2.26	103.77	1.80	97.33	1.58	93.39
BASMATI 123	2.37	109.27	2.29	105.97	2.67	99.33	1.59	95.37
BASMATI 370-1	3.85	107.80	3.77	104.50	3.46	98.00	2.63	94.05
GH 1837	2.63	108.53	2.55	105.23	2.53	98.67	1.78	94.71
Good & New	3.43	84.33	3.35	81.03	2.78	76.67	2.34	72.93
GR 18 RED	3.73	137.13	3.65	133.83	3.35	124.67	2.55	120.45
IR 72 (Ph)	3.75	138.60	3.67	135.30	3.37	126.00	2.56	121.77
KAWAWA RED	3.49	130.53	3.41	127.23	2.84	118.67	2.38	114.51
KOSHIHIKARI	4.47	169.40	4.39	166.10	3.78	154.00	3.06	149.49
Loc. Basmati-2	1.76	75.53	1.68	72.23	1.69	68.67	1.17	65.01
LOCAL RED	2.30	113.30	2.22	110.00	2.19	103.00	1.55	99.00
MATIGEY	5.59	169.40	5.51	166.10	4.84	154.00	3.85	149.49
PERFUME (ST)	2.10	142.27	2.02	138.97	1.83	129.33	1.41	125.07
Sebota 1	2.84	124.67	2.76	121.37	2.33	113.33	1.93	109.23
Sebota 147	3.65	101.20	3.57	97.90	3.13	92.00	2.49	88.11
Sebota 20*	3.01	109.27	2.93	105.97	2.71	99.33	2.04	95.37
Sebota 281-2	3.96	107.80	3.88	104.50	3.59	98.00	2.71	94.05
Sebota 33	2.57	100.10	2.49	96.80	2.21	91.00	1.74	87.12
Sebota 330	3.61	117.70	3.53	114.40	3.25	107.00	2.46	102.96
Sebota 337-1	2.90	112.20	2.82	108.90	2.66	102.00	1.97	98.01
Sebota 36	4.16	115.50	4.08	112.20	3.74	105.00	2.85	100.98
Sebota 41	4.59	123.93	4.51	120.63	3.71	112.67	3.15	108.57
Sebota 48	2.65	109.27	2.57	105.97	2.39	99.33	1.79	95.37
Sebota 63	3.55	108.53	3.47	105.23	2.80	98.67	2.42	94.71
Sebota 68	3.99	105.60	3.91	102.30	3.60	96.00	2.73	92.07
Sebota 69	5.55	116.60	5.47	113.30	4.69	106.00	3.82	101.97
Sebota 87	3.73	121.73	3.65	118.43	3.35	110.67	2.55	106.59
VIWORNOR	3.83	185.90	3.75	182.60	3.15	169.00	2.62	164.34
<b>Mean</b>	<b>3.44</b>	<b>121.90</b>	<b>3.36</b>	<b>118.60</b>	<b>3.00</b>	<b>110.82</b>	<b>2.35</b>	<b>106.74</b>
<b>Lsd (5%)</b>	<b>0.4</b>	<b>10</b>	<b>0.6</b>	<b>9.8</b>	<b>0.5</b>	<b>8.9</b>	<b>0.5</b>	<b>9.5</b>
<b>CV(%)</b>	<b>12.2</b>	<b>5.60</b>	<b>10</b>	<b>6.00</b>	<b>23</b>	<b>20</b>	<b>26</b>	<b>24</b>

The combined analysis of variance revealed that in terms of grain yield under the rainfed condition, significant differences ( $P < 0.05$ ) were observed for environments and highly significant differences ( $P < 0.01$ ) for main effect of genotypes as well as for the interaction of the genotypes and environments. For grain yield under the irrigated condition, however, there were highly significant differences ( $P < 0.01$ ) among environments (locations) and genotypes but not for the genotype by environment interaction. This observation demonstrates the possibility of crossover and non-crossover interactions in the GEI. Specific adaptation of a wide array of cultivars could have contributed significantly to

the GEI. The existence of significant differences ( $P < 0.05$ ) for environments and highly significant differences ( $P < 0.01$ ) for main effect of genotypes and the GxE for grain yield under the rainfed condition is an indication of differential genotypic performance across rainfed sites for grain yield. Similar reports on rice were earlier made by Blanche *et al.* (2009) and Sreedhar *et al.* (2011), which all revealed that GEI was significant, indicating differential response of genotypes to changes in environments while some genotypes showed stable performance over the range of environments. Furthermore, the existence of significant differences ( $P < 0.05$ ) for environments and highly significant differences ( $P < 0.01$ ) for

main effect of genotypes and the GEI is consistent with findings by Blanche *et al.* (2009) who reported greater effects for G and GxE than for E. Here again, this could be due to the wide range of cultivars included in the present study, which included different levels of homozygosity, grain types and origins of development.

From the combined analysis of variance for grain yield, the proportion of total sources of variation attributable to the genotypes was highest in both rainfed and irrigated sites, followed by other factors under error while blocks contributed least to the variation. This observation is at variance with the findings of Mohammadi *et al.* (2009) and Badu-Apraku *et al.* (1995, 2003), who reported that the largest proportion of total variation in multi-environment trials is usually attributed to locations (environments), with G and G x L sources being relatively smaller.

#### Genetic correlation between grain yield and other agronomic traits

Genetic correlations between rice grain yield (t/ha) and other studied traits at the 4 locations are presented Table 9. The genetic correlation coefficients between grain yield and other traits studied among the 30 rice materials were generally weak and negative, except for Days to 50% flowering (DFF), panicle weight (PAN Wt) and number of Panicles per hill (NO.P/HL) which were positive and strongly correlated to grain yield. For PAN Wt, all the correlation coefficient values were significant ( $P \leq 0.05$ ), except for that at Lagbani under rainfed condition. There was no consistent pattern for the correlation coefficients for most traits, including number of tillers three and six weeks after sowing / transplanting (3WAS, 3WAT; 6WAS, 6WAT) as they differed among locations and the production ecologies. The correlation between grain yield and 1000 grain weight (1000GWt) was not significant ( $P > 0.05$ ) under the two irrigation conditions, but were significant ( $P < 0.05$ ) at Nyangua and Lagbani. In terms of days to maturity (DM) and straw yield (Strw Yld), grain yield recorded non-significant ( $P > 0.05$ ) and negative correlations at all locations.

Table 9: Genetic correlations between rice grain yield at 14% moisture content (t/ha) and other studied traits in each of the 4 locations during the 2013 cropping season in the Guinea and Sudan savanna agro-ecological zones of Ghana

Parameter	Location			
	Irrigated ecologies		Rainfed ecologies	
	Tono	Libga	Nyangua	Largbani
NoT3WAS	-0.343	-0.111	-0.372	-0.250
NoT6WAS	-0.146	-0.167	-0.241	-0.319
DFF	0.746	0.734	0.528	0.424
PHM (cm)	-0.034	-0.041	0.110	-0.064
NO.P/HL	0.643	0.611	0.572	0.550
PAN Wt(g)	0.615	0.521	0.554	-0.413
DM	-0.105	-0.105	-0.363	-0.485
1000GWt(g)	-0.104	-0.203	-0.518	-0.524
Grain Lgth(mm)	-0.152	-0.171	-0.256	-0.247
Strw Yld	-0.443	-0.211	-0.272	-0.350

Generally, for the other parameters (traits) measured on the rice germplasm, there was no significant ( $p > 5\%$ ) genotype by location interaction effect. In addition, genetic correlation between grain yield and these traits was generally weak. The lack of significant genotype by location interaction effect for these traits indicated high stability across locations and hence their expression could hardly be influenced by the prevailing environmental variability of the locations sampled. The stability of these traits across the locations could be the reason for the weak genetic correlation between grain yield and these traits. On the other hand, days to 50% flowering (DFF), panicle weight (PAN Wt) and number of Panicles per hill were positively and strongly correlated to grain yield, an indication that these traits are unstable and easily affected by genotype by location interaction.

#### Adaptability studies of genotypes

Additive Main effect and Multiplicative Interaction (AMMI) ANOVA for grain yield of the 30 rice germplasm evaluated in the four environments confirmed that the genotype (G), environment (E) and their interaction (GEI) effects were significantly different ( $p < 0.01$ ), indicating that broad range of diversity existed among the genotypes. The results also showed that for the four environments considered, the highly significant differences ( $P < 0.01$ ) among environments and genotypes as well as the significance of GEI implies a highly significant influence of environment, genotype and their interaction effect on grain yield of rice genotypes within the Guinea and Sudan savannah zones. The IPCA 1 (56.89%) and IPCA 2 (33.62) interaction terms were significant ( $P < 0.05$ ) indicating the suitability of the AMMI model used.

Thus, multiple methods were employed to analyse stability, which coupled with mean analysis provided a good understanding of the adaptation levels of rice genotypes across the environments (Blanche *et al.* 2009).

In the AMMI analysis, the G x E interaction effect was further partitioned into IPCA scores. The analysis permitted estimation of interaction effect of a genotype in each location and thus helped to identify genotypes that best suited specific locations (Das *et al.*, 2010). The IPCA scores of a genotype in the AMMI analysis are an indication of the stability or adaptation over environments. The greater the IPCA scores, either negative or positive, (as it is a relative value), the more specifically adapted is a genotype to certain environments. The more the IPCA scores approximate to zero, the more stable or adapted the genotype is over all the

environments sampled. Thus, a genotype showing high positive interaction in an environment obviously has the ability to exploit the agro-ecological or agro-management conditions of the specific environment and is therefore better suited to that environment.

#### Combined analysis of variance of the AMMI 2 model

The combined analysis of variance according to the AMMI 2 model was performed using Genstat 12th Edition. The analysis showed that all the three components, i.e. genotype (G), environment (E) and their interaction (GEI) were highly significant ( $p < 0.01$ ). The GEI was further partitioned into 2 interaction principal component analysis axes (IPCA). The IPCA 1 and 2 were highly significant explaining 56.89% and 33.62%, respectively (Table 10), from the total GEI sum of squares indicating the variability relating to GEI. The IPCA1 and IPCA2 axes were highly significant ( $p < 0.01$ ) indicating adequacy of the AMMI model used.

Table 10: Analysis of variance (ANOVA) based on the AMMI model for grain yield (t/ha) for the four environments (locations)

Source	DF	SS	MS	Tot Var Expl(%)	GXE Exp(%)	Cum Exp(%)
Total	359	330.72	0.921			
Treatments	119	257.21	2.161**	77.77		
Genotypes	29	75.05	2.588**	22.69		
Environments	3	131.58	43.861**	39.79		
Block	8	1.82	0.228			
Interactions	87	50.57	0.581**	15.29		
IPCA 1	31	28.77	0.928**		56.89	56.89
IPCA 2	29	17.00	0.586**		33.62	90.51
Residuals	27	4.80	0.178			
Error	232	71.69	0.309			

\*\* $P < 0.01$ , Cum=Cumulative, Expl= Explained, Tot=Total, Var=Variation

In this study, the IPCA 1 (56.89%) was far greater than the IPCA 2 (33.62%), indicating differential yield performance among the materials across the testing environments due to the presence of significant G x E interaction effects. Therefore, in order to identify materials with grain yield stability and adaptation, studies on the magnitude and patterns of G x E interaction effects of specific sets of the materials is critical. Thus, the AMMI biplot based on the IPC1 scores regressed on environmental mean yields is considered an important measure of not only the pattern of adaptation, but also that of performance stability (Zobel *et al.*, 1988). Accordingly, genotypes with IPC1 scores close to zero showed better general adaptation than specific adaptation and vice versa (Ebdon and Gauch, 2002). For instance, IR 72 (pH) and Sebota 36 with respective IPC1 scores of 0.08916, and 0.07552 showed lesser differential response to the changes in the environments as compared to Viwonor and Sebota 281-2 with IPC1 scores of 0.70675 and 0.71191 respectively (Table 11). On the other hand, genotypes like Viwonor (0.70675) and Sebota 337-1 (0.48407) with larger positive IPC1 scores showed better specific performance at rainfed environments like

Nyangua. In contrast, Matigey with a larger negative IPC1 score (-0.62962) showed better performance at all four locations. Some genotypes also showed higher mean yields with relatively better performance stability across a range of environments. For example, the check material (GR 18) showed the lowest IPC1 score value (0.01471) with the sixth highest mean yield of 3.822 t/ha across the environments. The other five materials thus outperformed the check material indicating that these materials have the potential to increase rice productivity within the northern savannas and should therefore be recommended for further breeding and subsequently be released to rice farmers.

Genotypes such as Sebota 87, Matigey, Basmati 113, Sebota 68, IR 72 (Ph) and Sebota 36 showed the best adaptation to all environments but a little more so to the higher yielding irrigated environments. These genotypes are close to the origin (Figure 4) and tend to experience similar influence from the four environments. On the other hand, GH1837, GR 18, Basmati 123, Good and New, Perfume (ST) and Anyofula were also stable but more adapted to the higher yielding irrigated environments. These genotypes are

close to each other and tend to have similar grain yield performance. They are also close to the

irrigated sites thus indicating their specific adaptation to that particular environment.

Table 11: PCA1 and PCA 2 scores for the 30 entries sorted on mean yield and evaluated at 4 locations in 2013 in Northern Ghana

Entry	Genotype	Mean Yield (t/ha)	IPCAscore 1	IPCAscore 2
1	ANYOFULA	4.31	-0.21738	-0.06255
6	GH 1837	4.188	-0.167	-0.05218
4	BASMATI 123	4.123	-0.18186	0.06568
7	GOOD AND NEW (JP)	4.032	-0.13926	0.1296
15	PERFUME (ST)	3.921	0.05156	0.08084
8	GR 18 RED	3.822	0.01474	0.2172
17	Sebota 147	3.383	0.05597	0.43657
21	Sebota 330	3.282	-0.19548	0.2958
9	IR 72 (Ph)	3.272	-0.08916	-0.22683
12	LOCAL BASMATI – 2	3.157	0.11645	0.60386
27	Sebota 68	3.115	-0.47889	-0.14935
29	Sebota 87	3.113	0.34058	0.1205
14	MATIGEY	3.1	-0.62962	-0.007
3	BASMATI 122	3.094	0.38202	0.38363
26	Sebota 63	3.092	-0.04385	0.35342
2	BASMATI 113	3.09	-0.2706	-0.12359
23	Sebota 36	3.09	0.07552	0.12574
5	BASMATI 370-1	3.015	0.15476	0.22882
13	LOCAL RED	3.015	0.18609	0.16833
25	Sebota 48	3.015	-0.34503	-0.35437
16	Sebota 1	2.958	-0.29781	-0.11454
11	KOSHIHIKARI	2.917	0.37814	-0.51115
20	Sebota 33	2.896	0.32135	0.09012
18	Sebota 20	2.895	-0.1721	-0.53851
22	Sebota 337-1	2.887	0.48407	0.10426
30	VIWORNOR	2.876	0.70675	-0.51662
19	Sebota 281-2	2.754	-0.71191	0.01364
10	KAWAWA RED	2.75	0.20381	-0.23258
24	Sebota 41	2.725	0.2565	-0.34803
28	Sebota 69	2.719	0.21164	-0.1807

To graphically explain the GEI and adaptation of the entries to the environments, the AMMI model 2 biplot was used where the IPCA 1 scores were plotted against the mean yield (Figure 5). To further explain the GEI and adaptation, a biplot

between the AMMI analyses gave two significant AMMI components which accounted for over 90% of the G x E interaction sum of squares, of which the first AMMI explained 56.89% while the AMMI 2 explained a further 33.62% (Table 10).

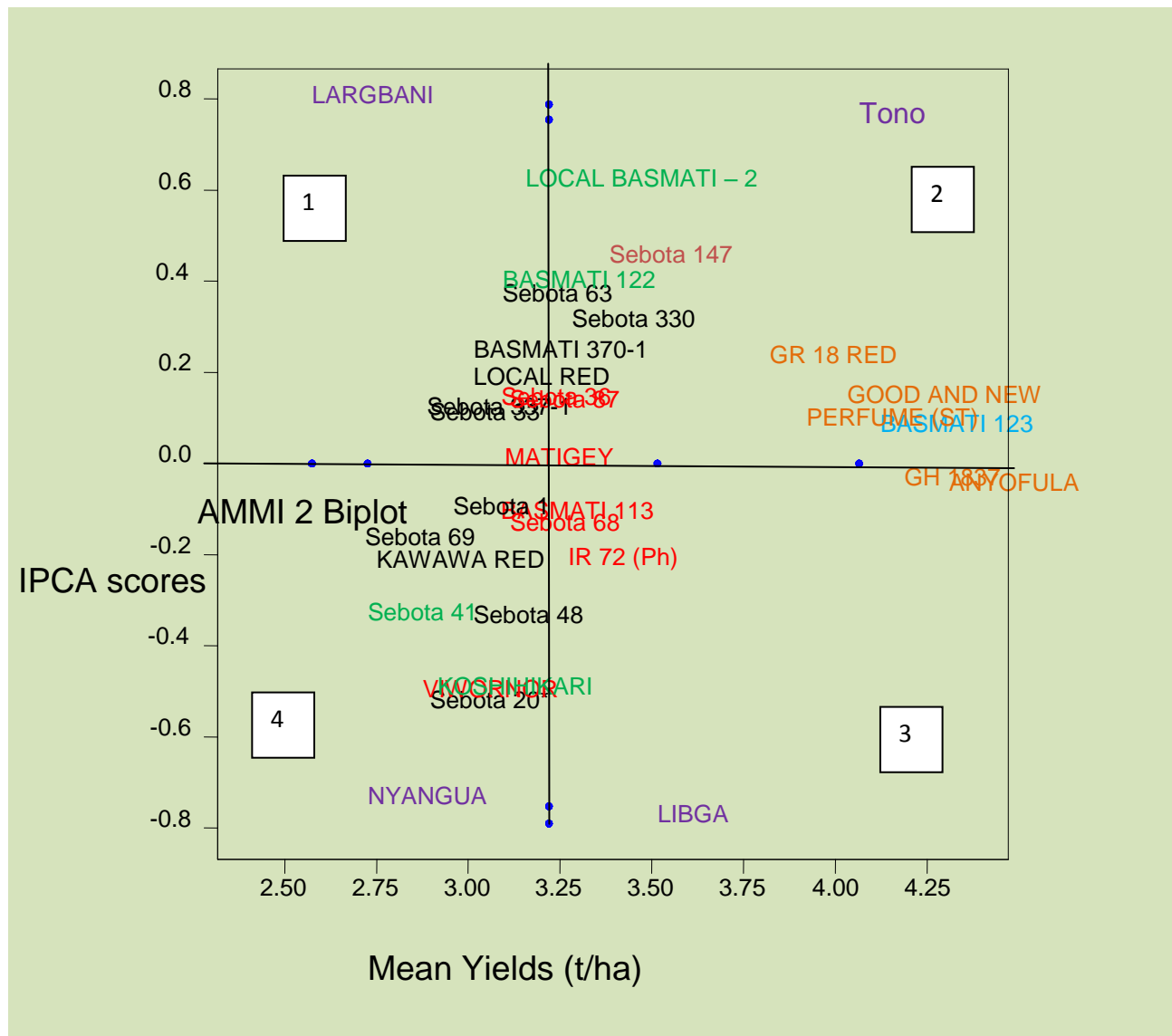


Figure 4: AMMI biplots of 30 rice genoplasm materials across four locations where ordinate is the Interaction Principal Component Axes 1(IPCA-1) scores and the abscissa is Genotype and Environmental mean grain yield

## CONCLUSION

The environments (locations) at which the experiments were conducted were geographically and temporally different, thus a large effect due to the environment was expected. Therefore, testing genotypes over different environments (locations) differing in unpredictable environmental variation is a suitable approach for selecting stable and adapted genotypes. The difference in grain yield performance of the genotypes in the various environments indicated the presence of significant genotype x environment interactions (GEI) for that trait. The combined analysis of variance according to the AMMI 2 model showed that all the three components i.e. genotype (G),

environment (E) and their interaction (GEI) were highly significant ( $p < 0.01$ ). The GEI was further partitioned into 2 interaction principal component analysis axes (IPCA). The IPCA 1 and 2 were highly significant explaining 56.89% and 33.62% respectively. Furthermore, the IPCA1 and IPCA2 axes were highly significant ( $p < 0.01$ ) indicating adequacy of the AMMI model used.

According to the AMMI 2 biplot, there was a broad range of diversity among the genotypes studied. Six genotypes, including Anyofula, Basmati 123, GH1837, GR 18, Good and New and Perfume (ST) showed superior grain yield performance and appeared to be specifically adapted to the higher yielding irrigated sites. Further, the other five materials, however,

outperformed the check material (GR18) indicating that these materials have the potential to increase rice productivity within the northern savannas and should therefore be recommended for further breeding and subsequently released to rice farmers. Even though Sebota 147 was also specifically adapted to the high yielding irrigated sites, it had below average stability. On the other hand, genotypes that were identified as broadly adapted to all the four environments (locations) included Sebota 87, Matigey, Basmati 113, Sebota 68, IR 72 (Ph) and Sebota 36. Genotypes that had above average stability, but were more specifically adapted to the lower yielding rainfed sites included Local Basmati-2, Sebota 20, Sebota 41, Viwornor and Koshihikari. Entries that showed no distinct patterns of adaptation and were specifically adapted either to lower or higher yielding environments included Sebota 330 and Sebota 48.

However, since this study was conducted under researcher's management, on-farm adaptive trials are required to validate these findings in order to arrive at conclusive recommendations for rice production within the Guinea and Sudan savannah zones.

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## APPENDICE

## Appendix 1: Guide to interpretation of soil analytical data by Prof.E.Y.Safo, KNUST (personal communication)

Soil variable	Range	Interpretation
Nitrogen (%)	>1.0	very high
	0.5-1.0	high
	0.2-0.5	medium
	0.1-0.2	low
	<0.1	very low
Phosphorus (mg/kg)	< 3.0	Low
	7.0-20	medium
	>20	adequate-high
Potassium (cmol/kg) <sup>a</sup>	0.05- 0.2	Low
	0.2-0.5	medium
	>0.5	high
pH	6.1-6.5	medium acid
	6.6-7.3	neutral
	7.4-7.8	mildly alkaline

<sup>a</sup> The range of 0.05-0.3 cmol/kg is usual for unfertilized soils in the humid region