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Abstract

Average yields of upland rice are the lowest in Uganda, and most of the productivity gains attributed to improved varieties are related to increased area of production from clearing virgin lands for rice production. In a bid to optimize productivity, we compared the effect of four nitrogen fertilizer treatments: 0, 40, 80 and 120 kgN/ha and two variety types (ITAs *(Oryza sativa)* and NERICAs (New rice for Africa)) on grain yield and yield parameters in four locations. Combined analysis of variance revealed that nitrogen fertilizer increased mean grain yields from 2116-5200 kg/ha in the NERICAs and 2331-5100 kg/ha in the ITAs. In all the study areas, NERICA 4 and NARIC 2 outperformed NARIC 1 and NERICA 1, and yield trends were consistent over the years suggesting that the two varieties respond better to N fertilizer application. However, the productivity gains are probably related to genetic potential of the varieties rather than the N fertilizer effect, as reflected by the consistent relative performance between 0 N and other N rates. The heavier grains of NARIC 2 and NERICA 4 suggest greater dry matter accumulation before heading, as these varieties have a longer period of vegetative growth. The significant interaction of location x fertilizer and location x variety reveals the need for evaluating the nitrogen-supplying power of soils in the various cropping systems in the country.

Keywords: ITAs, NERICA, Nitrogen fertilizer, Upland rice, Grain yield

1. Introduction

The popularity of upland rice in Uganda is fairly recent, and it is attributed to; a high rate of investment (1.8) among cereal crops (Kijima *et al.,* 2006), increased promotion by stakeholders, availability of improved rice varieties and increased demand and consumption, particularly, among the urban population and neighboring countries. However, the average yields are around 1.5 t/ha as opposed to 3.5 t/ha under irrigated conditions (Ogenga-Latigo, 1995; Odogola *et al.,* 2006). The low yields are largely a consequence of drought, low soil fertility (Briggs and Twomlow, 2002) and untimely weed management practices. In the last decade, the National Agricultural Research Organization (NARO) released four upland rice varieties (NARIC 1, NARIC 2, NERICA 4 and NERICA 1) with a potential to produce more than 4 t/ha. NERICAs (New Rice for Africa) are interspecific hybrids between the cultivated rice species *Oryza sativa* and *O. glaberrima* (Jones *et al.,* 1997) while NARIC 1 and NARIC 2 are *Oryza sativa* types designated as ITA 257 and ITA 325. These cultivars have rapidly spread in the country due to a high demand and higher yields relative to the traditional varieties. Like any rice cultivar, these varieties require fertile soil for high productivity. However, fertilizer use is a rare practice among the rural poor, and most of the productivity gains attributed to these varieties are related to clearing virgin lands for rice production. This is coupled with the absence of updated fertilizer recommendation rates for newer upland rice varieties in Uganda. Nitrogen is the most limiting crop nutrient in upland ecologies (Koutroubas and Ntanos, 2004) and its availability for plant growth is largely influenced by soil heterogeneity (Clark *et al.,* 2005, Boling *et al.,* 2008). Efficiency of nitrogen use is also variable among rice genotypes (Sheehya *et al.,* 1998; Zhou and Wang, 2003; Wang *et al.,* 2005; Saito *et al.,* 2006). However, when N-fertilizer is applied in the proper amount and at the correct time, N-fertilizer recovery up to 50–70% of total nitrogen applied can be achieved (Peng *et al.,* 1996; Peng and Cassman, 1998; Wang *et al.,* 2001; Ligeng *et al.,* 2004). Increased uptake of nitrogen influences the number of tillers, panicles and spikelets produced per square meter (Yoshida *et al.,* 1972), although with very high doses these increments are not significant. Where high doses of nitrogen are applied, there is an increase in the percentage of unfilled grains, some varieties being more sensitive than others in this respect (Hasegawa *et al.,* 1994; Horie *et al.,* 1997). Grain yield of rice is a combination of different yield components, such as the number of panicles per unit land area, the number of spikelets per panicle, the percentage of filled spikelets and the grain weight (Yoshida, 1983). The relative importance of each component varies with the location, cropping season, soil fertility, crop duration and cultural system (Koutroubas and Ntanos, 2004). The yield target for a given location and season is the estimated grain yields attainable with farmers' crop management when the constraints of N, P and K are overcome (Dobermann *et al.,* 2004). In Japan, two upland NERICAs (NERICA 1 and NERICA 5) exhibited superior biomass production and yield under rainfed upland conditions as compared with selected Japanese rice cultivars (Matsunami *et al.,* 2009). NERICAs were capable of absorbing greater amounts of N than the Japanese cultivars, a trait which, probably, contributed to the greater biomass production and grain formation, resulting in their higher grain yield. However, the NERICAs released for cultivation in Uganda have never been compared with other improved cultivars in response to nitrogen fertilizers. This study was designed to determine yield changes due to nitrogen levels and the influence of these on the yield components of the *Oryza sativas* and NERICA ecotypes.

2. Materials and Methods

Field experiments were conducted in 3 locations in Uganda: Iganga (Eastern), Masindi (Mid-Western) and Luweero (Central) during the year 2008 and 2009. All the experimental sites were typically upland rice production areas. One reference trial was established at the National Crops Resources Research Institute (NaCRRI), Namulonge. In all the locations, soil samples were collected from the trial plots before applying fertilizers and the samples were analyzed for soil nutrient status. The soil properties are briefly described in Table 1. The experiment involved four released popular varieties, NARIC 1 (ITA 257), NARIC 2 (ITA 325), NERICA 4 and NERICA 1. Nitrogen fertilizer was applied in form of soluble urea at four nitrogen rates: 0 kgN, 40 kgN, 80 kgN and 120 kgN/ha in split doses at 21 (tiller initiation stage) and 49 (active tillering stage) days after emergence. A basal application of 20 kgP_2O_5/ha in form of triple super phosphate and 20 kgK_2O/ha in form of Muriate of potash was done just before seeding to ensure that P and K were not limiting. The experiments were conducted in a split plot design, with nitrogen rates as main plots and varieties as sub plots. Three replications were established per location. Seeds were drill planted in furrows spaced at 30cm apart in randomized plots of 1.8 x 5 m size. Six rows were planted to each variety per plot and all plots received identical cultural treatments in terms of cultivation, seed rate (60 kg/ha) and pest management. Two middle rows in each plot were selected, and one meter from either side was randomly selected for recording plant height, tillers/m^2 and panicles/m^2. At maturity, panicles were harvested from either side of the tagged row plants and data on grain number per panicle was recorded. Grain yield, ripening ratio and 1000 grain weight were recorded from the harvest obtained from the selected four middle rows and the yield was expressed as kg/ha. The data was analyzed statistically with Fishers' analysis of variance technique at 5% probability level, combined over the years. LSD values were calculated and used to compare treatment means. Simple correlation coefficients were calculated based on treatment means.

3. Results

3.1 Site Soil Analysis

Analysis of soil samples from experimental sites revealed variability in nutrient and organic matter content (Table 1). Available N content was highest in Masindi followed by Namulonge. Lowest N content was recorded in Luweero and Iganga. Organic matter content was above the minimum requirement (>2%) in all the locations where the experiments were conducted. The P values recorded in the experimental sites were well above the critical soil levels (Mehlich-1 P <5-7 mg kg^{-1}P) for occurrence of P deficiency in uplands (Dobermann and Fairhurst, 2000). Potassium content was also above the critical deficiency (<0.2me/100g) limits in all the locations. This suggests that nitrogen was the most limiting nutrient in all the locations.

3.2 Response of Varieties across Locations

Combined analysis of variance for grain yield and yield components are shown in Table 2. Consecutive increase in N level significantly increased grain yield of all the rice varieties in all the locations with the highest grain yield obtained at 120 kgN ha^{-1}. Within each treatment, variety ranking in dry weight was similar to that for grain yield, and the results for the two years were consistent. For the location main effect, the highest grain yields occurred in Masindi and the lowest yields in Iganga (Table 3). A similar pattern of N response was observed when combined analysis over locations and nitrogen fertilization was performed (Table 4). Relative grain yield increment as a function of nitrogen fertilizer application in two years in four locations is shown in Figures 1-4. Yield curves generally show an upward trend except in Masindi where there was a decreasing trend. Means from the two highest treatments (80 and 120 kgN ha^{-1}) did not significantly differ from each other in Masindi and Luweero, but were distinct from the lower N treatments. The difference in yield response between the 2008 and 2009 seasons was apparent. Grain yields in 2009 were lower than in 2008 by about 12.4%, averaged across all varieties and fertilizer rates. In general, nitrogen fertilizer application increased grain yield by 46.7% in Namulonge, 56.7% in Luweero, 50.7% in Iganga and 46.8% in Masindi. There was significant effect of location, cropping seasons, variety and their interactions on performance.

3.3 Grain Yield and Yield Component Response to N Application

With the exception of NARIC 2, NERICA 4 produced significantly the highest grain yield than other cultivars at 120 kgN/ha in all the locations (Table 6). However, percentage increase in grain yield due to nitrogen was larger for NERICA 1 (52.7%) than for NERICA 4 (49.8%), NARIC 2 (49.3%) and NARIC 1 (49.3%). Plotting the yield performance of the four cultivars against their mean yield in the 16 environments (4 fertilizer rates and 4 locations) showed insignificant difference among the cultivars in regard to nitrogen response (Figure 5). However, significant differences were recorded in tiller and panicle production, and 1000 grain weight. NARIC 2 and NERICA 4 produced significantly higher number of tillers and panicles than NARIC 1 and NERICA 1. Application of 120 kgN/ha increased panicle number by 31.7% in NERICA 1, 30.6% in NERICA 4, 29.2% in NARIC 2 and 30.6% in NARIC 1. Tiller number increased by 48.0% in NERICA 1, 41.2% in NERICA 4, 41.4% in NARIC 2 and 46.8% in NARIC 1.

The number of spikelets per square meter (spikelet density) was significantly greater at 120 kgN/ha, and was one of the major contributors to the increased grain yield. Mean grains per panicle increased by 23.2% (averaged over locations and fertilizer levels), with the highest number obtained in NERICA 4 (113.1) followed by NARIC 2 (109.3). The 1000 grain weight was also significantly higher in NARIC 2 and NERICA 4 at 120 kgN/ha. The interaction pattern for 1000 grain weight was similar to that of the grain yield. The grain filling (ripening) ratio was not significantly different among varieties but there was a significant fertilizer x location and fertilizer x variety interactions in this aspect. Generally, the relationship in terms of response pattern between NARICs and NERICAs was relatively similar in all the traits measured.

4. Discussion

The two year experiments showed that nitrogen fertilizer application significantly increased rice yield, as has been reported previously (Yoshida, 1983; Pinheiro and de Castro, 2000; Wang *et al.,* 2002; Saito *et al.,* 2006; Haefele *et al.,* 2008). The mean grain yields increased from 2411 kg/ha with 0 N to 4842 kg/ha with 120 kgN/ha, suggesting that nitrogen fertilizer application is cardinal to increasing upland rice yields in Uganda. Grain yields continued to be linear at incremental rates of N fertilizer, suggesting that the present recommendation of 50 kgN/ha is insufficient for optimal upland rice productivity. In addition, the highest grain yields obtained at 120 kgN/ha compared to 40 kgN/ha showed that application of the latter is inadequate for optimum grain yield output. Conversely, there was no significant difference in grain yield between 80 kgN/ha and 120 kgN/ha in Masindi and Luweero, suggesting that the high organic matter content in the two locations significantly contributed to the high response to nitrogen fertilizer application at 80 kgN/ha. Linquist and Sengxua, 2001 reported an increase in indigenous nitrogen supply by almost 10 kg/ha and yield by 0.77 t/ha when adequate soil organic matter is available, confirming the importance of organic matter in complementing inorganic fertilizer application in upland rice cultivation. NERICA 4 significantly outperformed other cultivars in 2009, when there was relatively less moisture (data not shown), suggesting that NERICA 4 is more efficient in N utilization under water limited conditions than other varieties. Increase in grain yields of NERICA 4 is not a deviation of genotypic differences in relation to varietal characteristics. This cultivar consistently produced higher yields even under no fertilizer suggesting genotypic based response vis-à-vis grain yield increase due to N fertilizer application. These observations are similar to those of Pinheiro and de Castro (2000), in which upland rice yields of >5 t/ha with improved varieties have been reported in Brazil, and northern China (Wang *et al.,* 2002). Tiller and panicle number were significantly increased in all cultivars at 120 kgN/ha, and the trend was linearly related to grain yield. Studies by Yoshida *et al.,* (1972) indicate that as the amount of nitrogen absorbed by the rice crop increases, there is an increase in the number of tillers and panicles per square meter. Across locations, NERICA 4 and NARIC 2 produced the highest number of tillers and panicles/m^2 suggesting that the two varieties are probably more efficient in nitrogen utilization than NARIC 1 and NERICA 1. However, the higher percentage increase in the number of tillers compared with the increase in the number of panicles suggests that there was a wasteful production of tillers. NERICA 1 was previously found to absorb greater amounts of N than the Japanese cultivars, a trait which is thought, probably, to contribute to the greater biomass production and sink formation in the NERICAs (Matsunami *et al.,* 2009). Conversely, NERICA 4 (a new ecotype) and NARIC 2 (*Oryza sativa*) both outperformed NERICA 1 suggesting that nitrogen use efficiency coupled with genetic potential contributed to their high productivity over NERICA 1. NERICA 4 also produced the highest number of grains per panicle when compared to the other varieties. Previous studies have shown that rice plants generally differentiate excess spikelets depending on the nitrogen uptake ability (Horie *et al.,* 1997), some varieties being efficient in this aspect than others. NARIC 2 recorded a significantly higher 1000 grain weight than the rest of the cultivars tested. The heavier grains relate to sink capacity and efficiency of assimilate partitioning to the grains thus contributing to the high grain yield. Among the yield components, tillers m^{-2} and panicles m^{-2} had highest correlations with grain yield (r = 0.90 for both traits) (Table 7). Earlier studies also reveal a consistently close relationship between grain yield and yield components with nitrogen fertilization (De Datta, 1989; Kirrilov and Pavlov, 1989; Indira, 2005). This association is influenced by availability of nitrogen at critical stages of growth thus contributing to increased productivity. However, plant nitrogen utilization is associated with increased demand for P and K (Rajput et al., 1988; Dobermann and Fairhurst, 2000). This study did not consider varying P and K as it is reported elsewhere (De Datta, 1989; Dobermann and Fairhurst, 2000; Aulakh and Malhi, 2004; Goulding *et al.,* 2007). This is the first study to detect variety differences in the upland rice yield response to nitrogen fertilizer application under Ugandan upland rice agro-ecological conditions. Further research on evaluating and mapping nitrogen-supplying power of soils in the various cropping systems in the country is needed for area or agro-ecology specific technology package recommendations. The significant interaction of location x fertilizer and location x variety attests to this need.

5. Conclusion

The current N recommendation for improved upland varieties in Uganda is 50 kgN/ha. This recommendation is based on economic aspects rather than experimental data. Thus, it hides the potential associated with N application. The present study showed that grain yield and yield components responded positively to increasing rates of nitrogen fertilization. Based on the data, 80 kgN/ha or 120 kgN/ha is appropriate recommendation to realize optimum rice yields. In all the study areas, NERICA 4 and NARIC 2 outperformed NERICA 1 and NARIC 1, and yield trends were consistent over the years suggesting that the two cultivars are productive under high nitrogen doses. However, the productivity gains are probably related to genetic potential of the varieties rather than the N fertilizer effect, as reflected by the consistent relative performance between 0 N and other N rates. The current rate of 120 kgN/ha also points to the fact that there is decreased soil fertility because of continuous soil mining due to limited land and limited fertilizer use.

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Table 1. Soil fertility properties of experimental sites for variety response to nitrogen application in Uganda

Soil property	Iganga	Masindi	Luweero	Namulonge
pH	5.30	6.20	5.80	5.60
Organic matter (%)	3.02	7.90	5.21	4.81
Available N (%)	0.15	0.33	0.16	0.28
Exchangable P (mg/kg)	5.03	10.14	7.27	9.37
Exchangable K (me/100g)	0.39	0.51	0.37	0.39
Sand (textural %)	62.0	52.0	54.0	56.0
Clay (textural %)	24.0	34.0	24.0	34.0
Silt (textural %)	14.0	14.0	22.0	10.0

Table 2. *F* ratios from the combined analysis of variance for grain yield and yield components for four varieties evaluated under four nitrogen fertilizer rates in two years at four locations in Uganda

Source of var	d.f.	Grain yield	1000 Gwt	G pan^{-1}	Pan m^{-2}	Till m^{-2}	%G fill	Plant ht.
Location (L)	3	1590.34**	1584.65**	289.24**	262.79**	208.45**	20.44**	86.68**
Year (Y)	1	805.14**	1.20ns	119.56**	156.97**	143.66**	0.59ns	17.01**
Fertilizer (F)	3	3166.56**	256.83**	58.27**	735.54**	554.9**	12.34**	426.39**
Variety (V)	3	192.4**	31.85**	5.89**	37.08**	35.73**	2.74ns	141.59**
L x F	9	58.68**	7.05**	24.38**	5.63**	3.39**	0.44ns	4.91**
L x V	9	3.20**	4.52**	1.70ns	3.17**	2.75**	0.52ns	8.53**
L x Y	3	126.9**	2.61ns	61.01**	16.14**	15.71**	13.53**	100.63**
Y x F	3	19.89**	1.89ns	7.23**	6.35**	3.39*	0.63ns	6.59**
Y x V	3	0.39ns	0.29ns	4.41**	5.94**	4.12**	1.55ns	17.01**
F x V	9	4.24**	2.51*	2.02ns	1.70ns	1.8ns	0.30ns	2.20ns
L x F x V	27	1.74*	1.52ns	1.16ns	1.98**	1.52ns	0.45ns	2.18**
L x Y x F	9	59.26**	4.77**	30.91**	3.63**	2.33*	0.88ns	9.67**
L x Y x V	9	6.31**	1.28ns	3.54**	3.36**	2.95**	0.17ns	1.91ns
Y x F x V	9	1.92ns	1.30ns	1.64ns	0.94ns	0.66ns	0.63ns	0.49ns
L x Y x F x V	27	1.96**	1.20ns	1.59*	1.29ns	0.83ns	0.45ns	1.60*

**indicates significance of the F test at $p = 0.01$ *indicates significance at $p = 0.05$ and V, variety, Y, year; L, location; F, fertilizer

Table 3. Grain yield and yield components of four varieties grown under four nitrogen fertilizer rates at four locations in Uganda

	Grain yield (kg ha^{-1})	1000 Gwt (g)	Grain filling (%)	$Gpan^{-1}$	Pan m^{-2}	Till m^{-2}	Plant ht. (cm)
Location							
Namulonge	3642 b	24.68 a	0.91 b	100.1 b	231.4 c	248.2 c	97.05 b
Luweero	4090 c	31.13 d	0.85 a	117.6 d	240.5 d	257.6 d	99.25 c
Iganga	2449 a	25.64 b	0.91 b	79.8 a	188.1 a	200.5 a	91.69 a
Masindi	4522 d	30.20 c	0.91 b	105.5 c	218.4 b	232.4 b	97.10 b
N fertilizer (kgN/ha)							
0	2411 a	25.70 a	0.87 a	90.9 a	177.4 a	190.0 a	85.21 a
40	3292 b	27.26 b	0.89 ab	96.4 b	213.4 b	226.6 b	91.80 b
80	4158 c	28.69 c	0.90 bc	106.7 c	232.4 c	247.9 c	101.6 c
120	4842 d	29.99 d	0.92 c	109.0 c	255.2 d	274.0 d	106.5 d
% increase	*50.5*	*14.30*	*5.43*	*16.6*	*30.5*	*30.7*	*20.0*
Variety							
NERICA 1	3375 a	27.47 a	0.88 a	97.7 a	211.2 a	225.7 a	90.71 a
NERICA 4	3904 c	27.89 b	0.90 b	103.4 b	228.2 b	243.8 b	99.39 c
NARIC 2	3881 c	28.38 c	0.90 b	101.5 b	226.6 b	240.1 b	100.5 d
NARIC 1	3543 b	27.90 b	0.89 ab	100.4 ab	212.5 a	229.0 a	94.47 b
$LSD_{0.05}$ (loc main effect)	62.40	0.23	0.02	2.59	3.94	4.83	0.96
$LSD_{0.05}$ (Fert main effect)	64.90	0.40	0.02	3.87	4.20	5.21	1.61
$LSD_{0.05}$ (Var main effect)	54.60	0.19	0.01	2.85	4.33	4.24	1.12

Within columns, means followed by the same letters are not significantly different at 5% probability error

Table 4. Grain yield at 4 fertilizer treatments averaged over 4 varieties and that of 4 varieties averaged over 4 fertilizer treatments at four locations in Uganda

	Grain yield (kg ha^{-1})			
Locations	Namulonge	Luweero	Iganga	Masindi
Fert (KgN/ha)				
0	2502	2420	1742	2980
40	3220	3551	2057	4339
80	4148	4857	2464	5162
120	4697	5530	3532	5606
Variety				
NERICA 1	3352	3692	2267	4188
NERICA 4	3901	4329	2676	4708
NARIC 2	3876	4329	2624	4696
NARIC 1	3439	4008	2229	4496
Location means	3642	4090	2449	4522
$LSD_{0.05}$ (L x F)				112.3
$LSD_{0.05}$ (L x V)				226.1

Table 5. Grain yields of the 4 varieties averaged over 4 fertilizer treatments in two years

N fertilizer (kgN/ha)	Grain yields (kg/ha)			
Year 2009 (Mar-July)	NERICA 1	NERICA 4	NARIC 2	NARIC 1
0	1921	2317	2422	2023
40	2784	3253	3087	2902
80	3375	3844	3899	3655
120	4230	4887	4816	4308
Year 2008 (Aug-Nov)				
0	2311	2901	2755	2639
40	3281	3711	3823	3493
80	4389	4802	4862	4435
120	4708	5512	5384	4887
LSD (Year main effect)				44.1
LSD (Y x V)				81.8
LSD (Y x F)				84.0

Table 6. Mean grain yield of four varieties under four fertilizer treatments for four locations in Uganda

	Grain yield (kg/ha)			
Variety	0N	40N	80N	120N
NERICA 1	2116	3032	3882	4469
NERECA 4	2609	3482	4323	5200
NARIC 2	2588	3455	4381	5100
NARIC 1	2331	3198	4045	4598
Mean	2411	3291.7	4157.8	4841.8
$LSD_{0.05}$ (F x V interraction)				108.2

Table 7. Correlation of grain yield and yield components across locations, nitrogen fertilizer and varieties

	Grain yield (kg ha^{-1})	*1000 Gwt (g)*	*Grain filling (%)*	*Gpan^{-1}*	*Pan m^{-2}*	*Till m^{-2}*
Grain yield (kg ha^{-1})	1					
1000 Gwt (g)	0.78	1				
Grain fill (%)	0.30	-0.16	1			
Gpan^{-1}	0.85	0.80	-0.22	1		
Pan m^{-2}	0.90	0.62	0.22	0.84	1	
Till m^{-2}	0.90	0.61	0.21	0.84	1.00	1

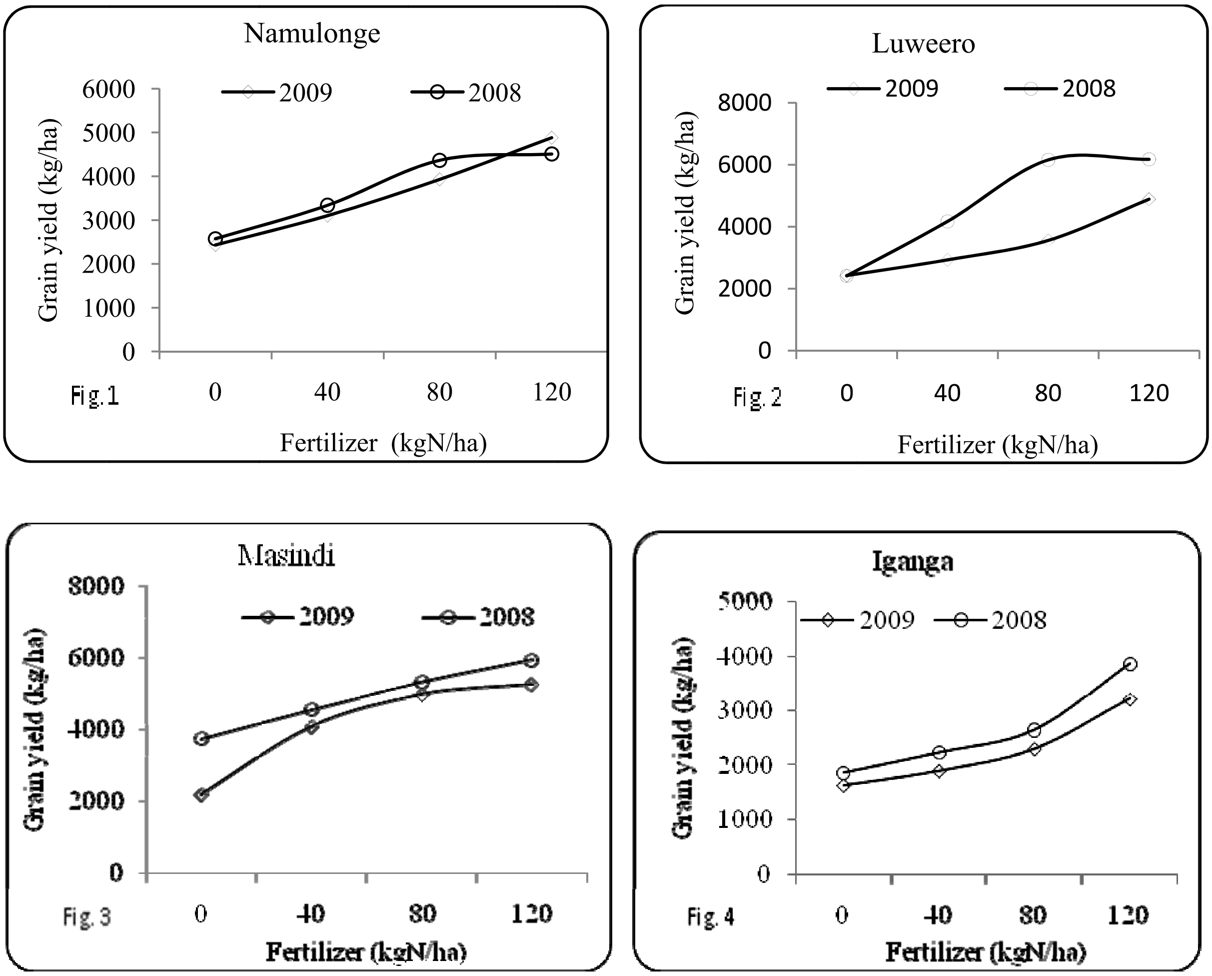

Figure 1-4. Grain yield increase in 2 years averaged over 4 fertilizer rates at different locations in Uganda

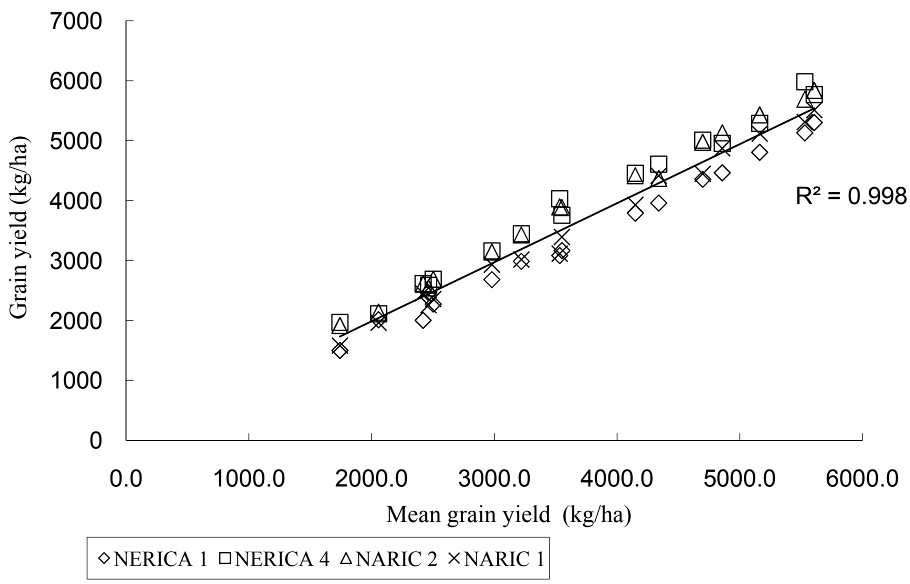

Figure 5. Relationship between mean grain yield of four varieties and grain yield of each variety in 16 environments (four locations by four N fertilizer treatments)