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Effects of nitrogen rates and preceding crops on the growth and productivity of upland rice in inland valley

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Abstract

The study was conducted to determine the effects of upland rice and lowland preceding varieties, and N fertilization on growth and productivity upland rice grown the same year in two locations in the inland valley of Nigeria. The experiment was split plot design with two preceding lowland rice varieties (Jasmine and Funaabor-2) as main plots and five levels of N (0, 30, 60, 90 and 120 kg N ha^{-1}) for the succeeding upland rice as split plot treatments with 3 replications. Results showed that upland rice grown after FUNAABOR-2 variety gave significant ($p < 0.05$) number of leaves, chlorophyll content, number of tillers, dry matter, , panicle per m^2, panicle weight and grain yield than Jasmine variety was the preceding crop. Rice grown after Funaabor-2 exhibited 54% grain yield increments compared to growing Jasmine in Igbogila. The effects of preceding lowland rice varieties on the yield components and grain yield of upland rice was pronounced more in Alabata (671 kg ha^{-1}) than Igbogila (1077 kg ha^{-1}). Similarly, linear responses to N application from 0-120 kg ha^{-1} were observed on the growth and yield components of rice in both locations. Thus, Cultivation of Funaabor-2 and increasing the rate of N application from 90 to 120 kg ha^{-1} is recommended to boost rice growth and yield, increase profitability and to enhance long-term sustainability of the cropping system in inland valley.

Keywords: cropping sequence, nitrogen, lowland rice, productivity, yield

Introduction

Rice (*Oryza sativa* L.) is an important food crop in the world. It is a means of livelihoods to millions of people with a tremendous significance of alleviating poverty and malnutrition in most part of sub-Sahara Africa (SSA) (Basorun 2009). It can be refined into rice bran, oil, rice cakes, and other foods products. Human consumption accounts for around 85 percent of global rice production. This could be attributed to the changes in the demographic profile of the populace and its ease of preparation (Idris et al. 2013). In Nigeria, there is significant opportunity for the production of rice and can be one of the major sources of income for smallholder farmers due to the booming demand for rice as a result of the rapidly growing population. However, the productivity of rice is low in most part of SSA countries including Nigeria. This could be attributed to production constraints among other factors. Rice grows in varied agroecologies on the continent including inland valleys. Akinbile (2007); Nascente and Kromocardi (2017) reported a grain yield in upland rice of 0.8–3.0 t ha^{-1}, which is considerably lower than those reported for the upland rice of 5–7 t ha^{-1} (Oyekanmi et al. 2008). However, the sustainable production of upland rice could be compromised in the long run due to the scarcity and inconsistency of rainfall in upland environments. Production of upland rice in inland valleys could serve as an alternative option in the face of the earlier highlighted challenges, especially among resource-challenged farmers. However, despite this optimism production of upland rice is constrained by both abiotic and biotic factors. Thus, there exists a paradox whereby there are plenty of opportunities, but a scarcity of rice due to very low production of rice in Nigeria. This low rice productivity in the country is associated with different biophysical stresses and management constraints, including soil fertilization and application methods (Tanaka et al. 2017).

In developing countries, soil fertility is the most important factor that limits crop yields. As a result, 50% of the increase in crop yields is due to the use of inorganic fertilizers (Baligar, Fageria, and He 2001). Rice production in the Nigeria inland valleys is constrained by collective effects of physical and biotic factors including soil fertility depletion, soil acidity, weed infestation, disease incidences, drought and use of very low external inputs. Among all essential elements, nitrogen (N) ranked first in terms of quantities and is required in large amounts for plant growth. It is the major component of deoxyribonucleic acid (DNA), ribonucleic acid (RNA), essential amino acids and proteins. Nitrogen is also a central component of the chlorophyll molecule, which is essential for the photosynthetic process (Alva et al. 2006). Among N management practices in Nigeria, nitrogen fertilizer rates and time of applications would be responsible for increasing the nitrogen use efficiency and productivity of rice in inland valleys.

Nitrogen is easily disappeared from the soil surface when there is mismanagement in rice fields due to its very mobile nature as compared to phosphorus and potassium nutrients. It is lost through various mechanisms including volatilization, denitrification, leaching, and runoff. These losses of N should be minimized by synchronizing improved nitrogen fertilizer application methods with optimum N fertilizer rates for the various growth stages of rice. Besides of minimizing the N losses, the practice of leaving rice fields in the lowlands or inland valleys to fallow or used for late-season vegetable cultivation is likely the main reason for the current low productivity of rice. The question of how to reduce the nitrogen application level and improve nitrogen use efficiency as rice plants attaining high yield and good quality has become an important research focus in these days (Kumar et al. 2018). To aid N management, a better understanding of the roles of preceding crops and application of optimum level of N is needed.

Presently practiced nitrogen fertilizer rate recommendations is claimed to be not suitable to rain-fed upland rice while nitrogen losses are not minimized. Thus, seeking appropriate nutrient nourishing mechanisms and increasing the productivity through impacts of proceeding crops and at its optimum rates is highly important for sustaining rain-fed upland rice production in the inland valleys. Effects of cropping sequences and application of N fertilizer rates to rain-fed upland rice production systems in inland valleys is not yet tested so far in Nigeria. Therefore, the aim of this study was to investigate the effects of preceding crops (lowland rice varieties) and N fertilizer rates on the productivity upland rice in inland valleys of South-western Nigeria.

Materials and methods

Description of the study locations

The field trials were conducted on farmers' fields in the Alabata and Igbogila in 2012 cropping season in Ogun State, Nigeria. Alabata (7⁰, 20N, 23E) and Igbogila (7⁰, 12N, 3E) are potential districts for rice production and categorized as tropical humid. Both districts is tropical derived savanna and is characterized by bimodal rainfall pattern with two distinctive seasons (dry and wet). The dominant soil type of both districts is *kandic paleustalf* in the *Alfisol* order of the United States Department of Agriculture (USDA) soil taxonomy. The study site in Alabata district was located at latitude 7º 20′ North, longitude 3º 23′ East at an altitude of 174 m above sea level. The mean annual temperature was 27.5°C, and the annual rainfall was 783.7 mm. The study site in Igbogila district was located at latitude 7º 12′ North, longitude 3º 3′ East at an altitude of 85 m above sea level. There were no established weather station in the study site in Igbogila.

The soil physical and chemical properties of the soil (0–20 cm) were determined using standard protocols. The particle size distribution (clay, silt, sand) was determined using the hydrometer method and soil pH (1:1 soil: water ratio) using glass electrode pH meter (Mclean, 1983). The organic carbon using Walkley–Black wet oxidation method as modified by Allison (1965), available phosphorus using the Bray No. 1 method (Bray and Kurtz 1945), total nitrogen using Kjeldahl distillation method (Bremner and Mulvaney 1982) and exchangeable basic cations using ammonium acetate method (Moss 1961). Table 1 shows the physico-chemical properties of the soil at the experimental site before the commencement of the trial. The textural class of the soil at Alabata was loamy sand in texture with 78 g/kg and 84.4 g/kg sand, 7 g/kg and 62 g/kg clay and 15 g/kg and 94 g/kg silt particle at Alabata and Igbogila. The soil at Alabata and Igbogila was moderately acidic with pH of 6.06 and 4.64. However, the soil at Alabata and Igbogila was very low in organic carbon (1.79 % and 1.04 %) and thus low in organic matter content and total nitrogen (0.7 % and 0.58 %). Exchangeable potassium (1.15 cmol kg^{-1} 0.54 cmol kg^{-1}), available phosphorus (Bray 1 P) of the soil was low (1.65 ppm and 6.6

ppm). Exchangeable magnesium was high (8.17cmolkg^{-1} and 4.08 cmolkg^{-1}) though the exchangeable calcium was high at Alabata (9.15 cmol kg^{-1}) and low at Igbogila (0.43 cmol kg^{-1}). The exchangeable sodium percentage at Alabata and Igbogila was also (1.63 cmol kg^{-1} 1.29 cmol kg^{-1}).

Experimental treatments and design

The experiments in both locations were a year sequential and performed in fixed plots at each of the site (one at each location). It was designed in split plot with preceding lowland rice varieties (Jasmine and FUNAABOR-2) as main plot and five levels of N (0, 30, 60, 90 and 120 kg N ha^{-1}) for the succeeding crop (upland rice *var* NERICA-8) as sub plot treatments with 3 replications. The preceding rice varieties in the respective locations were sown in randomized complete block design with 3 replications. Three week old seedlings of the two lowland rice varieties were transplanted into the main plots at 20 cm x 20 cm spacing in July 2012 at both locations and the field was irrigated on daily basis for 3 weeks. Thereafter, irrigation was suspended to supply 400 kg of NPK 20: 10:10 was applied across all treatments at three weeks after transplanting. Irrigation continued a week after fertilizer application until physiological maturity. After harvesting, the rice straw was incorporated into the soil.

The main plots were divided into 5 sub plots with an equal size of 80 m^2 (10 m by 8 m). The spacing between plots and blocks were 0.5 m and 1 m, respectively. Three weeks old-seedlings of upland rice (NERICA 8 variety) were transplanted in October 2012 in both locations and N fertilizer was applied to the upland rice at 3 WAT at the rate of 0, 30, 60, 90 and 120 kg N ha^{-1}. In addition, all relevant agronomic practices were undertaken as per the local recommendations for rice.

Data collection

The measured (computed) variables for growth, grain yield and yield attributes were Chlorophyll content (measured using chlorophyll metre: SPAD 502), plant height, number of tillers, number of leave, dry matter, number of days to 50% flowering, panicle length, panicle weight, panicle m^{-2}, grains per panicle and grain yield number For grain and aboveground biomass yields measurements, the entire crop was harvested from a net plot area of 46 m^2 (6 m by 8 m). The number of tillers per each plant was counted from 5 plant samples from each plot. Plant heights from the ground surface to tip of the plant were measured at physiological maturity based on 5 plant samples per plot. The whole harvest from each plot was subjected to drying and weighing for the determination of aboveground total biomass yields. The air-dried samples were threshed manually, cleaned and weighed for grain yield determination. The weighed samples of the aboveground biomasses and grains from each plot were converted to kg ha^1 for statistical analyses.

Statistical analysis

The growth variables, yield and yield components data were subjected to analysis of variance (ANOVA) using Genstat statistical package 12 edition. The differences among the means were separated using least significance difference at 5% level of probability.

Results and discussion

The statistical analysis of variance of the two locations indicated that preceding crops (lowland rice varieties) and nitrogen (N) fertilization significantly influenced the growth variables (Tables 2 and 3), yield components and grain yield of upland rice (Tables 4 and 5). However, there were no significant interaction effects between preceding crops and N fertilizer for the variables measured or computed except for the number of leaves, chlorophyll reading and dry mass in Abeokuta (Table 2, and number of grains in Igbogila

(Table 5). Hence, the main effects of preceding crops and N fertilizer have been presented below.

Effect of preceding crops on growth variables and productivity of upland rice

Results indicated that preceding crops significantly influenced the growth variables, grain yields and yield components of upland rice in both locations. Analysis of variance showed that upland rice grown after FUNAABOR-2 variety gave significant ($p < 0.05$) number of leaves, chlorophyll content, number of tillers, dry matter and number of grains per panicle increments than when Jasmine variety was the preceding crop in Abeokuta (Tables 6 and 7). Similar result was observed in Igbogila with very significant ($p < 0.001$) plant height, number of leaves, panicle per m^2, panicle weight and grain yield increments than when Jasmine variety was the preceding crop (Tables 8 and 9). The effects of preceding lowland rice varieties on the yield components and grain yield of upland rice was pronounced more in Alabata than Igbogila (Tables 8 and 9). The mean grain yields of upland rice succeeding FUNAABOR-2 in Igbogila and Alabata were 671 and 1077 kg ha^{-1} respectively.

Generally, the superior productivity of the upland rice following cultivation of FUNAABOR-2 variety compared to when Jasmine was the preceding variety indicated the vital advantage of cropping sequence with FUNAABOR-2. This impact of FUNAABOR-2 may have been related to the lower penetrometer resistance, which was characteristic to deep tap roots on soil structure (Amanuel et al., 2000). Lower penetrometer resistance indicates reduction in soil compaction and bulk density; thereby enhances infiltration of rainfall and increases moisture retention as opposed to runoff in compacted soils. Other factors may have been related to reduction of soil N mineralization (Przednowek et al., 2004). The N residue left after the harvest of FUNAABOR-2 could have attributed to the increased yield of the subsequent upland rice. Thus, the amount N residue left behind in the soil for subsequent crops is generally related to the yield that the previous crops attained (Przednowek et al., 2004).

Effect of nitrogen fertilizer on growth variables and productivity of upland rice

The application of N fertilizer markedly influenced the growth variables (Tables 2 and 3), yield and yield components (Tables 4 and 5) of upland rice in both Alabata and Igbogila. The influence of N fertilization on the number of leaves, chlorophyll reading number of tillers and dry mass of upland rice were significant both for the Abeokuat (Table 2) and Igbogila (Table 3). The results showed that the number of leaves (Figure 1 a and b), SPAD chlorophyll reading (Figure 2 a and b), number of tillers (Figure 3 a and b) and dry mass (Figure 4 a and b) of the upland rice increased with increased rates of N fertilizer application for Alabata and Igbogila respectively. N fertilization increased the plant height of the upland rice in Igbogila, with no effect in the Alabata study area (data not shown).The highest number of leaves for Alabata (Figure 1a) and Igbogila (Figure 1b) sites were recorded for the application of 120 kg N ha^{-1} (44 and 52 respectively). This study generally showed that N fertilization increased the tillering capacities of the upland rice compared to unfertilized plots. The number of tillers plant^{-1} increased with increased rates of N fertilizer application both locations (Figure 3a and b).

N fertilization significantly affected the number of grains per panicle (Figure 5a and b), panicle per m^2 (Figure 6a and b), panicle weight (Figure 7a and b) in both locations as indicated by significant linear responses to increasing N rates. The biggest responses were recorded from the highest rate of N (120 kg N ha^{-1}) in Alabata and Igbogila. Generally, N fertilization improved the grain yield and yield components for Alabata and Igbogila study areas increased as the rate of N fertilizer increased from 0 to 120 kg N ha^{-1}. The lowest grain yield in Alabata (257 kg ha^{-1}) and Igbogila (349 kg ha^{-1}) were recorded from the plots not treated with N fertilizer (Figure 8a and b).

The response of upland rice to N fertilization and the lack of a significant interaction between pre-crop and N rate showed that grain and biomass yields increased with increased rates of N in both locations irrespective of preceding varieties. Accordingly, the agronomic optimum rate of N for enhanced upland rice productivity was 120 kg N ha^{-1} for the Alabata and Igbogila locations regardless of preceding varieties. Several researchers (references) also reported similar results of increased rice grain yield with increased N fertilization rates. Similarly, increased rice biomass yields with increased N fertilization rates were also reported based on several global studies. O'Donovan et al. (2014) also reported higher yield potentials owing to application of N fertilizer after preceding crops.

Similar to the preceding crops, the effects of N fertilizer on the biomass and grain yield of upland rice was pronounced more for the Alabata than Igbogila sites. Higher incremental responses to N fertilization and lower yield for the Alabata compared to Igbogila sites could partially be attributed to the relatively lower initial N content (0.58%) and soil pH (4.64) for the Igbogila than the relatively higher initial N (0.7%) and soil pH (6.06) for the Alabata sites. Increased rice panicle weight with increased N fertilizer rates was also reported in previous studies. Similar to the effect of cropping sequence, the mean panicle weight of upland rice for the Alabata was somewhat higher than the Igbogila sites, which could be attributed to the relatively higher initial phosphorous concentrations in the soil for the Alabata (26.1 mg kg^{-1}) site compared to Igbogila (6.6 mg kg^{-1}) site, and to its consequent positive impact on seed formation. This is because phosphorus is a vital component of ATP, which is formed during photosynthesis. Photosynthesis has phosphorus in its structure, and involves in the processes from seedling growth through to seed formation and maturity (Malhotra et al., 2018). Increase in panicle weight with increase in P application was reported in previous studies. Owing to its role in good root growth (Malhotra et al., 2018), phosphorus directly affects the panicle weight (Hussain et al., 2006).

The promoted plant tillers in Alabata site attributed to the enhanced N availability due to increased rates of N. The application N fertilizer promotes tillers development as it increases the cytokinin content within tiller nodes of the culm and further boosts the growth of the tiller primordium (Sakakibara et al., 2006). Thus, tiller formation depends largely on the N absorbed and the carbohydrates produced at the growth stage when the tiller primordium grows or upon the nutrients stored in the culm. N deficiency results in fewer numbers of tillers, which consequently produce a smaller population of panicles m^2 (Prystupa et al., 2003; Mitchell et al., 2012). Conversely, surplus of surviving tillers due to excessive N can lead to a larger population resulting in higher competition for limited resources (Wang et al., 2009). Adequate supply of N rate, therefore, optimizes productive tiller density and enhances grain yield. Results further revealed that the number of panicles per m^2 and number of grains per panicle of upland was significantly influenced by N fertilization, indicating the contribution N for enhanced plant growth. The current result was is consistent with the reported findings of O'Donovan et al. (2011).

Conclusion

The present study demonstrated that upland rice sown preceding lowland rice varieties, and increased rate of nitrogen fertilizer irrespective of preceding varieties, improved upland rice yield. As a result of higher yields and increased economic benefits, cropping sequences of lowland rice-upland rice along with fertilizer rates of 120 kg N ha^{-1} regardless of preceding crops can be used as alternate management options to sustain rice productivity in inland valleys for the trial sites located in Alabata and Igbogila locations of the South-western Nigeria. This recommendation can be extended to other regions of similar agro-ecologies in the country and other parts of the world. The preceding lowland variety, particularly FUNAABOR-2 and N fertilizer rates have the potential to increase rice production, while promoting enhanced economic returns for smallholder farmers and sustain the supply of rice grain for human and livestock consumption. In the current study, the cut-off point for the maximum nitrogen fertilizer rates was not reached, while the response to nitrogen fertilizer was linear in this study. Therefore, further investigation is recommended to determine the response curve for nitrogen fertilizer after each preceding crop over long periods at representative locations across the major rice producing areas in Nigeria.

Table 1: Pre-planting Physico-Chemical properties of experimental soils

Soil Physico-chemical properties	ALABATA	IGBOGILA
Sand	78 g/kg	84.40 g/kg
Clay	7 g/kg	6.20 g/kg
Silt	15 g/kg	9.40 g/kg
pH	6.06	4.64
Mg($Cmol^{-1}$)	8.17	4.08
Na($Cmol^{-1}$)	1.63	1.29
K($Cmol^{-1}$)	1.15	0.54
H+ Al	0.11	0.74
ECEC	20.21	7.08
% Base SAT	99.46	89.55
C %	1.79	1.04
N %	0.70	0.58
P(ppm)	26.10	6.60
Cu(ppm)	1.65	1.95
Mn(ppm)	187.50	20.75
Fe(ppm)	845.00	79.00
Zn(ppm)	22.00	3.70

Table 2. P values from the analysis of variance for the effects of preceding lowland rice varieties and N fertilizer rate on growth variables of upland rice in Alabata.

Effects	Plant height (cm)	Number of leaves	Chlorophyll reading	Number of tillers	Dry matter (g)
Preceding rice (PR)	0.841	0.040	0.150	0.048	0.040
Nitrogen rate (N)	0.533	0.016	0.004	0.040	0.027
PR*N	0.435	0.022	0.048	0.107	0.045

Table 3. P values from the analysis of variance for the effects of preceding lowland rice varieties and N fertilizer rate on growth variables of upland rice in Igbogila.

Effects	Plant height (cm)	Number of leaves	Chlorophyll reading	Number of tillers	Dry matter (g)
Preceding rice (PR)	<0.001	0.001	0.142	0.472	0.103
Nitrogen rate (N)	0.020	0.001	0.006	<0.001	<0.001
PR*N	0.140	0.544	0.066	0.434	0.258

Table 4. P values from the analysis of variance for the effects of preceding lowland rice varieties and N fertilizer rate on yield and yield components of upland rice in Alabata.

Effects	Number of grains per panicle	Panicle m^{-2}	Panicle length (cm)	Panicle weight (g)	1000-grain weight (g)	Grain yield (kg ha^{-1})
Preceding rice (PR)	0.029	0.780	0.191	0.299	0.392	0.946
Nitrogen rate (N)	0.017	0.029	0.053	0.043	0.416	<.0.001
PR*N	0.058	0.917	0.907	0.117	0.199	0.954

Table 5. P values from the analysis of variance for the effects of preceding lowland rice varieties and N fertilizer rate on yield and yield components of upland rice in Igbogila.

Effects	Number of grains per panicle	Panicle m^{-2}	Panicle length (cm)	Panicle weight (g)	1000-grain weight (g)	Grain yield (kg ha^{-1})
Preceding rice (PR)	0.122	<0.001	0.023	0.026	0.356	<0.001
Nitrogen rate (N)	0.025	<0.001	0.003	0.013	0.536	<0.001
PR*N	0.004	0.078	0.080	0.052	0.902	0.464

Table 6. Means for the main effect of preceding lowland rice varieties on the growth variables of upland rice in Alabata.

Preceding rice variety	Plant height (cm)	Number of leaves	Chlorophyll reading	Number of tillers	Dry matter (g)
Jasmine	83.6	31.6^{b}	46.8	10.1^{b}	32.2^{b}
FUNAABOR-2	82.4	36.4^{a}	45.1	13.4^{a}	36.3^{a}

Note: (1) means with the same letter are not statistically different, (2) values without letters indicated insignificant responses.

Table 7. Means for the main effect of preceding lowland rice varieties on the growth variables of upland rice in Igbogila.

Preceding rice variety	Plant height (cm)	Number of leaves	Chlorophyll reading	Number of tillers	Dry matter (g)
Jasmine	83.9^{b}	37.1^{b}	37.3	10.6	27.0
FUNAABOR-2	92.9^{b}	42.1^{a}	39.1	11.2	29.2

Note: (1) means with the same letter are not statistically different, (2) values without letters indicated insignificant responses.

Table 8. Means for the main effect of preceding lowland rice varieties on the yield and yield components of upland rice in Alabata.

Preceding rice variety	Number of grains per panicle	Panicle m^{-2}	Panicle length (cm)	Panicle weight (g)	1000-grain weight (g)	Grain yield (kg ha^{-1})
Jasmine	76.3^{b}	20.8	52.5	2.63^{b}	28.0	672
FUNAABOR-2	105.4^{a}	21.5	51.5	3.13^{a}	28.3	671

Note: (1) means with the same letter are not statistically different, (2) values without letters indicated insignificant responses.

Table 9. Means for the main effect of preceding lowland rice varieties on the yield and yield components of upland rice in Igbogila.

Preceding rice variety	Number of grains per panicle	Panicle m^{-2}	Panicle length (cm)	Panicle weight (g)	1000-grain weight (g)	Grain yield (kg ha^{-1})
Jasmine	72.5	47.7^{b}	20.5^{b}	3.57^{b}	32.9	491^{b}
FUNAABOR-2	78.5	56.2^{a}	21.9^{b}	3.94^{a}	33.9	1077^{a}

Note: (1) means with the same letter are not statistically different, (2) values without letters indicated insignificant responses

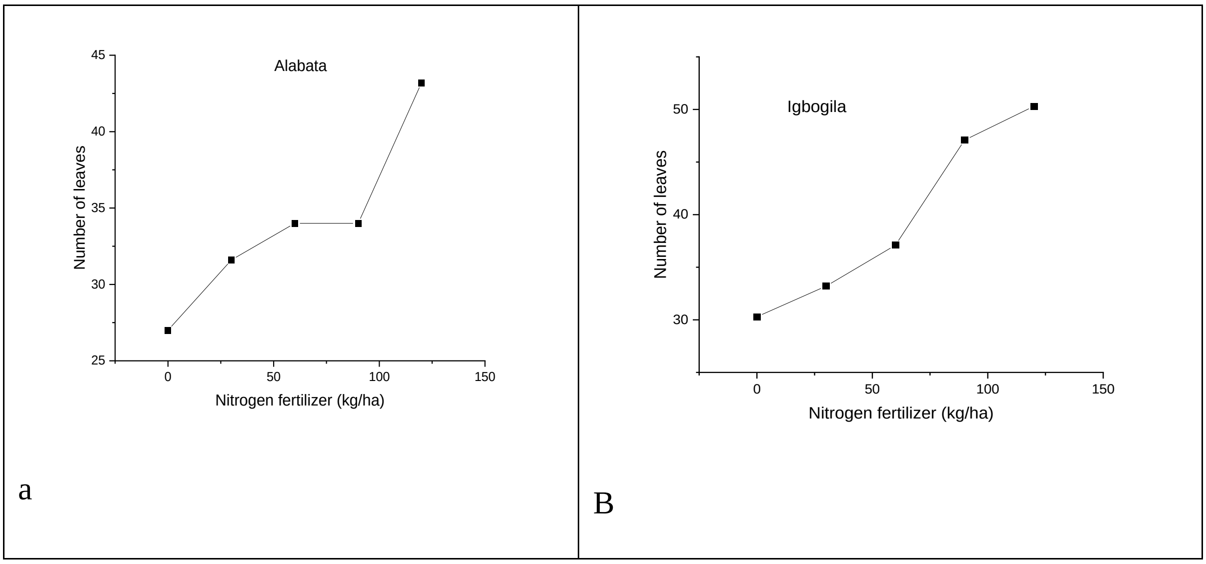

Fig. 1: Effect of N fertilizer rates on number of leaves at Alabata (a) and Igbogila (b)

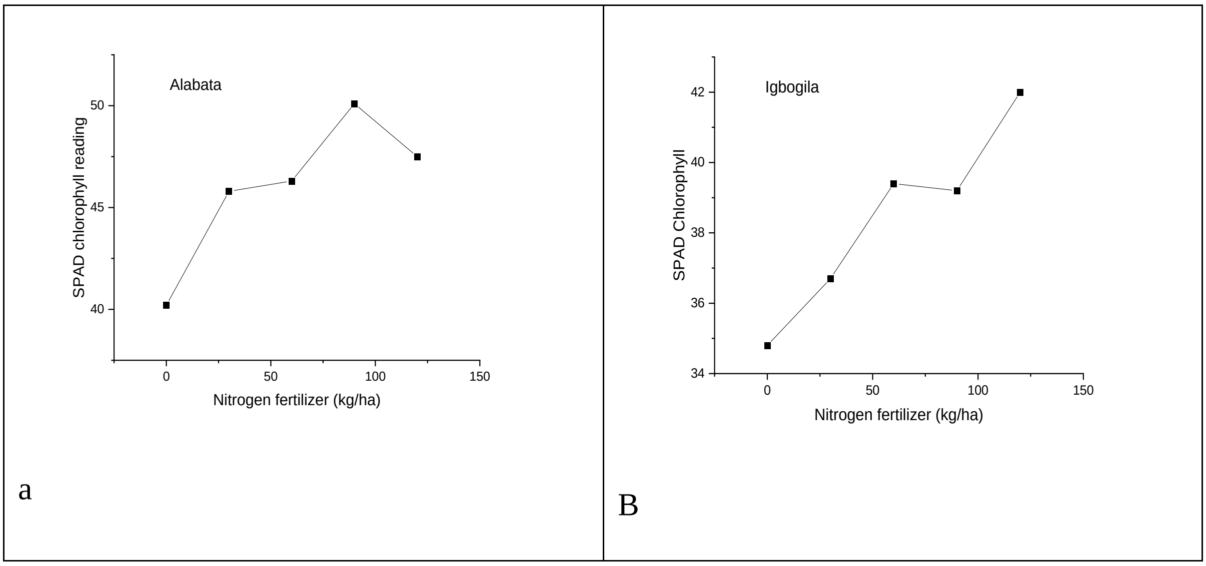

Fig. 2: Effect of N fertilizer rates on SPAD chlorophyll at Alabata (a) and Igbogila (b)

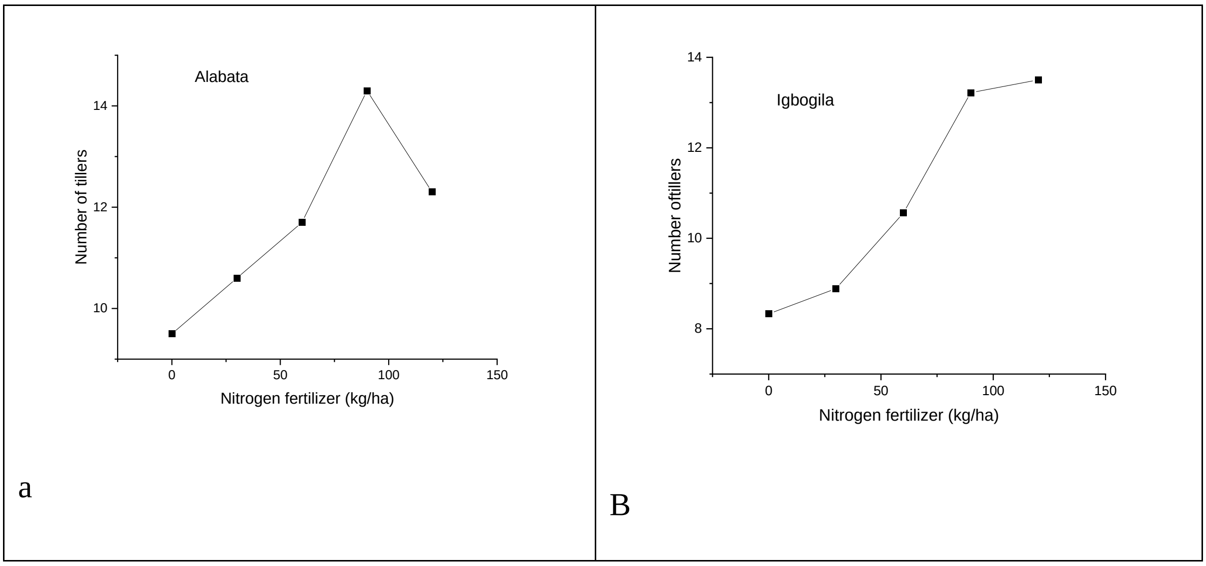

Fig. 3: Effect of N fertilizer rates on number of tillers at Alabata (a) and Igbogila (b)

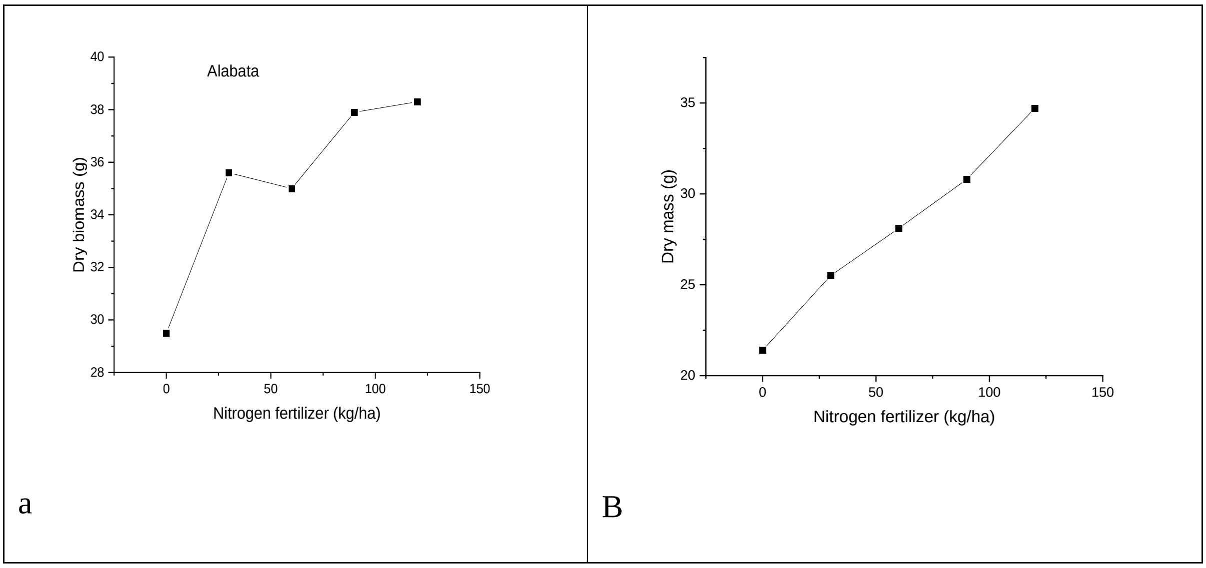

Fig. 4: Effect of N fertilizer rates on dry mass at Alabata (a) and Igbogila (b)

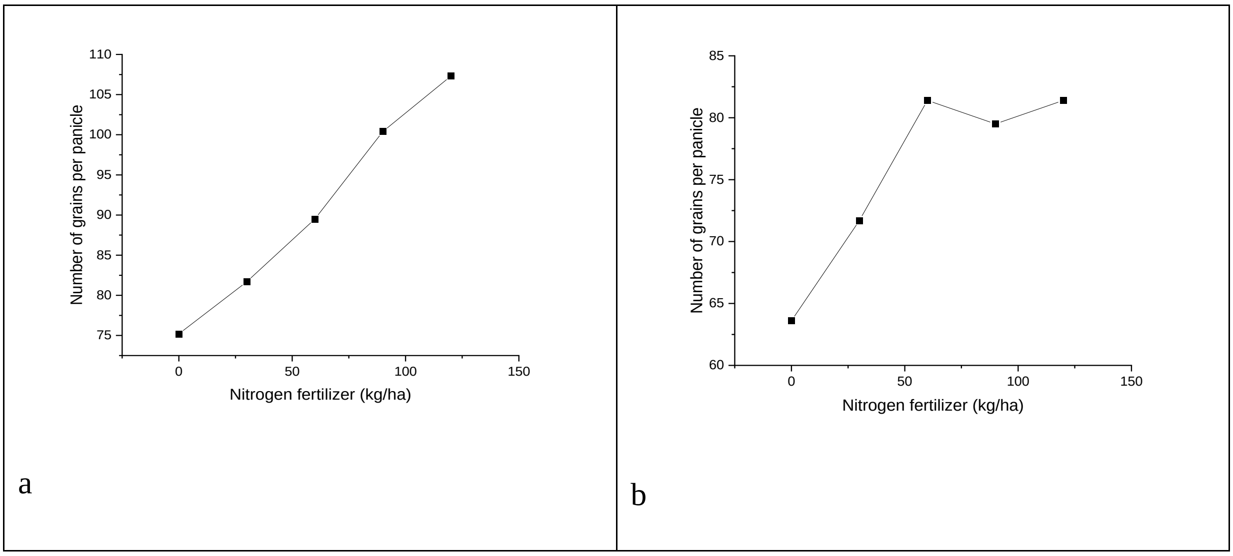

Fig. 5: Effect of N fertilizer rates on number of grains per panicle at Alabata (a) and Igbogila (b)

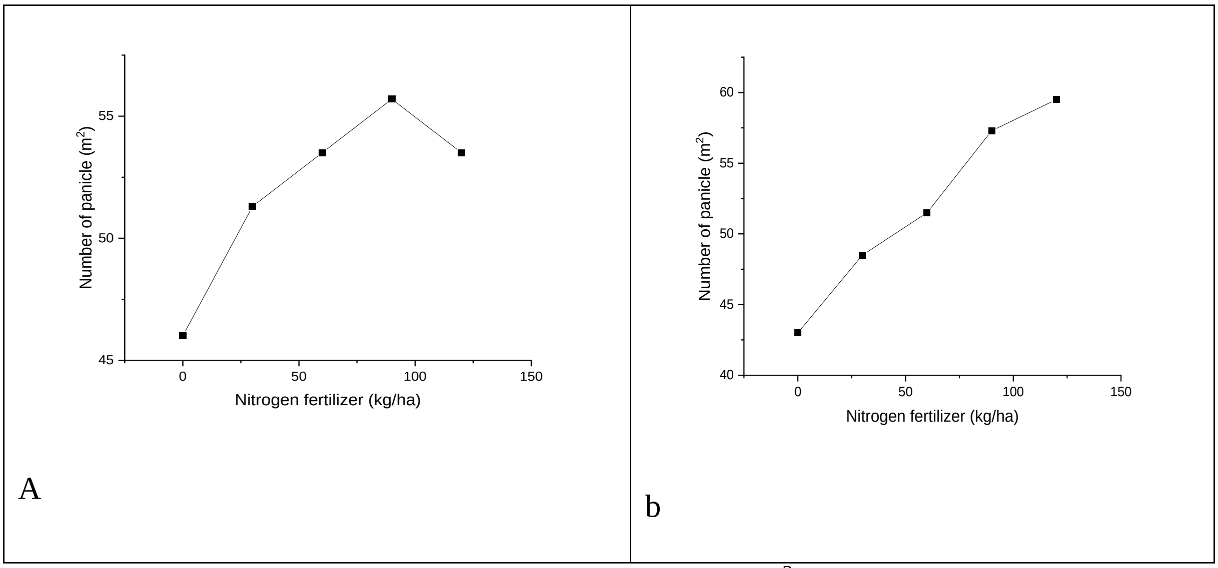

Fig. 6: Effect of N fertilizer rates on number of panicles per m^2 at Igbogila (a) and Alabata (b)

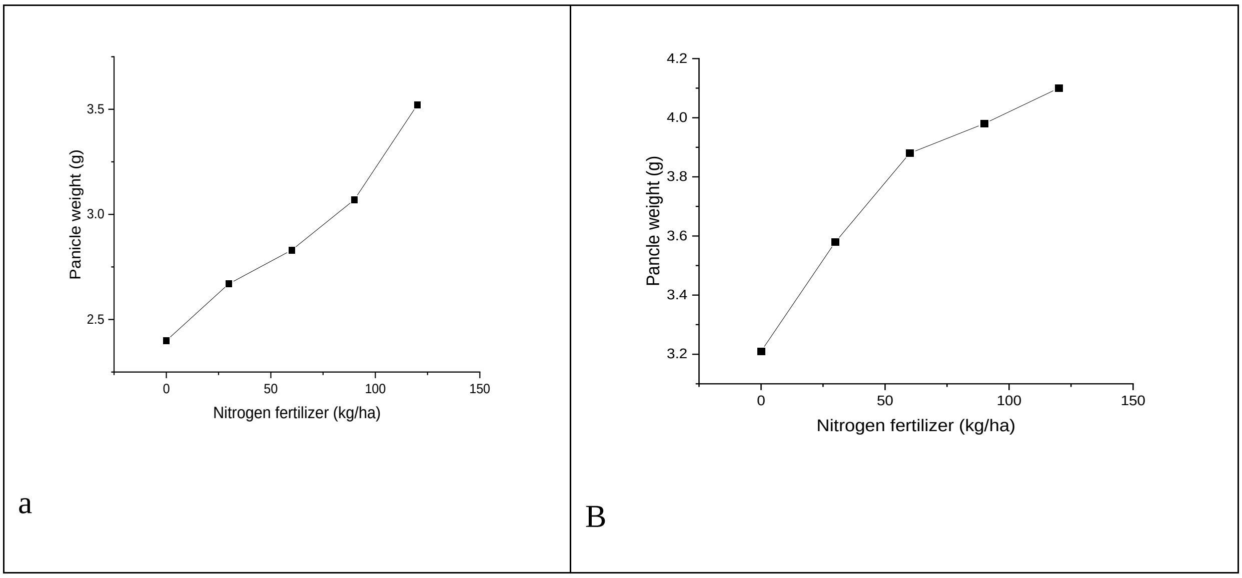

Fig. 7: Effect of N fertilizer rates on panicle weight at Igbogila (a) and Alabata (b)

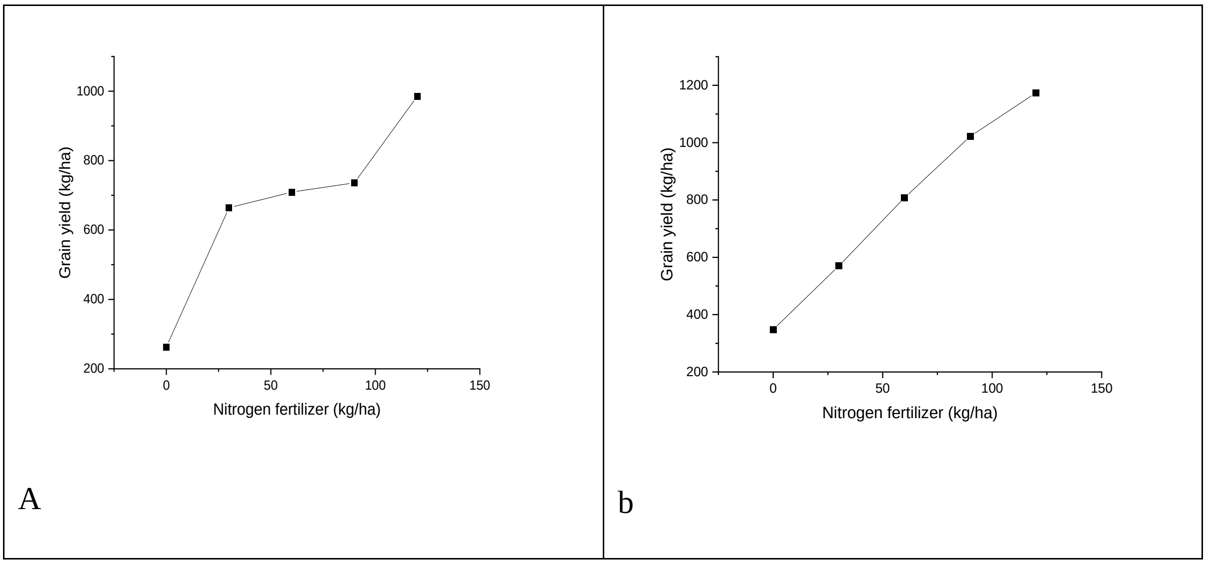

Fig. 8: Effect of N fertilizer rates on grain yield at Igbogila (a) and Alabata (b)

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