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Agronomic Evaluation of Some Drought Tolerant NERICA Rice Varieties to Arbuscular Mycorrhizal Fungi (AMF) Inoculation in the Rainforest Transitory Zone of Nigeria

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Abstract

Erratic rainfall distribution pattern poses serious challenge to food production in the rainforest transitory zone of Nigeria. Low input technology through the adoption of drought tolerant varieties (NERICA) and the application of Arbuscular Mycorrhiza Fungi (AMF) inoculum could be an alternative option for double cropping of upland rice. Field trials were conducted in the Teaching and Research Farm of the Federal University of Agriculture, Abeokuta in the early and late cropping season of 2012 in the transitory rainforest agro-ecology of Nigeria. The objective was to investigate the performance of some selected upland NERICA rice to the application of AMF inoculum. A 6 x 2 factorial experiment was conducted; six upland rice varieties selected with and without the application of AMF, laid out in split plot arrangement, with AMF in the main block, while variety was in the sub-plot. Each treatment was replicated three times. In both seasons, significant ($P < 0.05$) effect of AMF inoculation was observed on vegetative, reproductive growth and development parameters in the order + AMF > - AMF. In the early season there was no significant ($P > 0.05$) varietal variability on grain yield/ha. Conversely, in late season NERICA 4 recorded significantly ($P < 0.05$) higher grain yield (1050kg/ha) as suggested in significantly ($P < 0.05$) higher panicle/m^2 (59.50). Performance of NERICA 4 was significantly increased by application of AMF inoculation in the late cropping season.

Keywords: Arbuscular Mycorrhiza Fungi (AMF), NERICA rice, low input technology, drought tolerance, double cropping

1. Introduction

Food security challenges in Nigeria are exacerbated by demographic pressures in the context of dwindling resources. Rice forms a major part of most people's diet in Nigeria and by extension most population in the developing part of the world (Dowling, Greenfield, & Fisher, 1998). Its production is been constrained by abiotic and biotic factors; water in particular. One solution towards meetings this challenge is double cropping of rice in Nigeria, since available environmental resources could support such a strategy. However, erratic rainfall distribution pattern poses a serious threat. Efforts in the recent were placed on the availability of low input technology; introduction of NERICA rice, which was regarded as a veritable alternative to other existing varieties (Dingkuhn, Johnson, Abdoulaye sow, & Audebert, 1999; Audebert, Dingkuhn, Manty, & Johnson, 1998). NERICA rice had been demonstrated to be less demanding in terms of resources, with comparatively appreciable performance (M. Matsunami, T. Matsunami, & Kokubun, 2009).

It was reported that application of Arbuscular Mycorrhiza Fungi (AMF) could aid crops in the modification of plant water relations, especially in water limiting conditions (Auge, 2001; Davis, Potter, & Linderman, 1992;

El-Tohamy, Schnitzler, El-Behairy, & El-Betagy, 1999). AMF was found to be responsible for the accumulation of compatible osmolyte; proline and sugar in tissues (Ruiz-Lozano, 2003; Kubikova, Moore, Ownlow, Mullen & Auge, 2001; Auge, Foster, Loescher, & Stoda, 1992). Others functions reported involve modification of root architecture and increase in hyphal volume towards the capture of more water by crop plant in a water limiting condition (Marulanda, Azcon, & Ruiz-Lozano, 2003; Kothari & Marschner, 1990). Others involve protective function during the commencement of degenerative reactions in crops under stress conditions; oxidative reaction, cytosolic acidiosis and denaturation of macromolecules (Ruiz-Lozano, Azcon, & Palman, 1996; Ruiz-Lozano, Collados, Barca, & Azcon, 2001a). Aside of its function during moisture deficit, it was also reported to be responsible for the uptake of some essential macro and micro nutrients; especially the uptake of phosphorus, nitrogen, magnesium and zinc (Yeasmin, Zaman, Rahmanr, Absarl, & Khanum, 2007).

In the light of the prevailing abiotic stressors; water and nutrient deficiency encountered in the tropical region of Nigeria, there is a need to put in place ameliorative strategies to improve the performance of lowland rice in the rainforest transitory zone of Nigeria. Hence the objective of this study was to evaluate the effect of the application of AMF on the growth, development and yield of drought tolerant NERICA rice varieties grown in the rainforest transitory zone of Nigeria.

2. Materials and Methods

2.1 Description of Location and Experimental Site

Field trials (early and late seasons) were conducted at the upland section of the Teaching and Research Farm of the Federal University of Agriculture, Abeokuta (FUNAAB) between May 26 - September 4, 2012 (first trial) and September 8- December 8, 2012 (second trial). However, Moroberekan was harvested late being a late maturing variety in both trials. The agro-ecology of FUNAAB (7°9′ 38.9″ N lat., and 3°21′ 53.9″ E long.; 140 m asl) is a transition between rainforest and derived savannah. The total rainfall during the period of experimentation in FUNAAB was 1164.1 mm (Table 1). The average temperature during the period was 27.4 °C (Table 1). Soil samples were collected for the determination of chemical properties before planting and after harvest (Table 2). Soil pH was determined in 1:2.5 (soil: water) and KCl solution (1:1) using glass electrode pH meter. Soil organic matter was determined according to Walkey and Black (1934) method. Total nitrogen in the soil was analysed using Kjeldahl method (Bremner, 1960). Available phosphorus was extracted using Olsen's extract while the P in the extract was determined by the use of spectrophotometer. Exchangeable cation (K, Ca, Mg) were extracted with 1 N Ammonium Acetate K in the extract was determined by flame photometry, Ca and Mg were determined by atomic absorption spectrometer (AAS).

Table 1. Monthly distribution and annual mean temperature and total rainfall at the experimental site, 2012

Month	Temperature, °C	Rainfall, mm
January	27.0	0.00
February	28.8	67.2
March	29.1	67.7
April	28.5	80.1
May	27.7	115.3
June	26.9	225.1
July	26.0	155.4
August	25.5	36.3
September	26.2	181.4
October	27.2	184.7
November	28.2	49.6
December	28.8	1.30
Total		1164.1

Source: Federal University of Agriculture, College of Environmental Resources Management, Department of Agricultural Meteorology and Water Management.

Table 2. Chemical properties of the soil at different trials and treatments

S/n	Soil treatments	PH	Organic carbon	Organic matter (%)	Total nitrogen (%)	Phosphorus (ppm)	Potassium (ppm)	Magnesium (ppm)	Calcium (ppm)
1	Before planting	5.7	1.55	2.88	0.13	33.22	0.26	1.90	16.10
2	Early trial after harvest without Mycorrhiza inoculation	5.8	1.86	2.57	0.15	28.45	0.18	1.10	15.40
3	Early trial after harvest With Mycorrhiza inoculation	7.4	2.10	3.29	0.19	195.79	0.24	2.00	15.30
4	Late trial after Harvest With Mycorrhiza inoculation	7.2	1.99	3.06	0.18	125.32	0.19	2.00	12.40
5	Late trial after Harvest without Mycorrhiza inoculation	5.2	1.11	2.34	0.12	22.84	0.11	1.30	12.50

2.2 Experimental Design and Treatment

A 2 x 6 factorial experiment with Arbuscular mycorrhiza (with and without AMF) and six varieties of upland rice (NERICA 1, NERICA 2, NERICA 3, NERICA 4, WAB56-104, and Moroberekan) was conducted. The study was a split plot arrangement in Randomized Complete Block Design (RCBD), with AMF inoculation in the main plot, while varieties were in the sub-plot, replicated three times.

2.3 Source and Application of AMF

Arbuscular mycorrhizal fungi inoculum was obtained from the Department of Plant Physiology and Crop Production of the Federal University of Agriculture, Abeokuta. The pure inoculum of *Funneliforms* species (Glomus mosseae and Glomus geosporum) isolated from the rice fields across Nigeria was prepared according to Brundrett (2004). The mixed inoculum of the two *Funneliforms* species was applied to the hole where rice seeds were planted under the treatment with mycorrhizal at the rate of 50 g per hole just before the seeds were planted.

2.4 Cultural Practises

Rice was planted at a spacing of 20 cm x 20 cm by dibbling method. Plot size was 4 m x 3 m (12 m^2), each sub plot consisted if 21 rows of rice/plot, 16 plants per row and 336plants/plot. This is equivalent to 250,000 plants/ha at 3 seeds/hole.

2.5 Sampling and Data Collection

Five plants per plot were randomly selected from the net plot (2 x 2 m) for the collection of agronomic parameters (growth, development, yield and yield components) of upland rice varieties. Plant height, number of tillers and dry matter accumulation were recorded at 4, 8 and 12 weeks after planting (WAP). Plant height was determined using a ruler from soil surface to the tip of the tallest leaf. Harvested sampled plants were oven dried till constant weight at a temperature of 70 °C, weighted on a scale. Development parameters (Days-to-50% flowering and days-to-90% maturity) were determined by standard procedures. Number of panicle per meter square was determined with the aid of one meter quadrant by counting the number of panicle in the quadrant three weeks before harvesting. Other yield components parameters were determined by standard procedures.

2.6 Statistical Analysis

Data collected were subjected to Analysis of Variance (ANOVA), mixed model at 5% probability level. All data were checked prior to statistical analysis for the violation of ANOVA assumption and transformed using square root transformation. Means were separated using DMRT. Genstat 12th Edition statistical package was used for the analysis.

3. Results

3.1 Growth Response

Plants inoculated with AMF were significantly ($P < 0.05$) taller than those without AMF during both the seasons (Tables 3 and 5). In the early season, significant ($P < 0.05$) varietal variability was observed in plant height only at 4 WAP, while in the late season, significant ($P < 0.05$) varietal variability was observed across all the period of investigation. WAB 56-104 had significantly higher plant height than other varieties in the late season. However, Moroberekan did not emerge in the late season. Significant interaction ($P < 0.05$) of AMF x variety was observed in both seasons on plant height, except at 4 WAP.

Number of tiller was significantly ($P < 0.05$) increased by AMF application at 8 and 12 WAP in both seasons (Tables 3 and 5). There was no significant difference ($P > 0.05$) in the number of tillers among the varieties. But in the late season significant ($P < 0.05$) differences were observed at all phenological phases. More tillers were observed in the early season (Table 3) than in the late season (Table 5) among the varieties. In the early season significant ($P < 0.05$) AMF x variety interaction was observed in the 12 WAP. While in the late season it was observed across all the phenological period of investigation.

Table 3. Effect of AMF inoculation on growth parameters of upland rice varieties, early cropping season (2012)

Treatments	Plant height (cm)			Number of tillers			Dry weight (g)		
	4 WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP
Mycorrhiza(M)									
Without	39.87b	72.21b	92.62b	2.78	5.28b	4.61b	0.73	1.55	3.55b
With	45.26a	82.33a	107.27a	3.17	6.39a	5.39a	0.80	1.70	4.05a
SE±	0.58	0.72	1.34	0.15	0.29	0.22	0.13	0.11	0.16
Varieties (V)									
NERICA® 1	42.15ab	77.18	98.97	3.17	6.00	5.00	0.83ab	1.75	3.66bc
NERICA® 2	43.16a	70.19	94.38	3.17	6.00	4.83	0.68bc	1.83	3.83ab
NERICA® 3	40.1b	68.42	95.38	2.67	5.67	4.67	0.64bc	1.56	3.19c
NERICA® 4	41.98ab	71.81	96.72	2.83	5.17	4.67	0.52c	1.42	3.76bc
Moroberekan	44.07a	88.8	108.39	2.83	6.83	6.17	0.93a	1.57	4.42a
WAB 56-104	43.94a	87.24	105.83	3.17	5.33	4.67	1.00a	1.67	3.94ab
SE±	1.00	1.24	2.33	0.26	0.50	0.37	0.23	0.19	0.27
M*V	ns	*	*	ns	ns	*	*	ns	ns

For each variable, means followed by the same letter in the column are not significantly different by DMRT test.

In both seasons, dry matter accumulation was significantly higher with AMF than without AMF inoculation at 12 WAP. Significant varietal differences were observed at both early and late season. In the early season, at 4 and 12 WAP Moroberekan was significantly higher in dry matter accumulation than NERICA 2, 3 and 4 and NERICA 1, 3 and 4 respectively. In the late season, WAB 56-104 had higher accumulation of dry matter; however at 4 and 12 WAP it was not significantly different from other varieties. Significant interaction ($P < 0.05$) of AMF x variety was observed on dry matter accumulation in the early season at 4 WAP, while in the late season it was observed across all phenological stage of investigation except at 4 WAP ($P > 0.05$).

3.2 Development, Yield and Yield Components Response

All yield components were significantly ($P < 0.05$) affected by the application of AMF in both seasons (Table 4 and Table 6). In the early season, days-to-50% flowering and days-to-95% physiological maturity were significantly higher in plants without AMF inoculation compared to inoculated plants. However, panicle length and weight, number of seed/panicle and yield were significantly higher in inoculated plants. In fact the yield of rice in inoculated plants was more than 150% higher than the yield of non-inoculated plant. All development parameters were significantly ($P < 0.05$) affected by AMF inoculation except days-to-50% flowering in the late season. In the early season NERICA 1 (3.49 g) had significantly ($P < 0.05$) higher panicle weight than other varieties examined except NERICA 3 (3.38 g). In the late season NERICA 1 and WAB 56-104 had significantly higher panicle weight than other varieties. Significant interaction ($P < 0.05$) of AMF x variety was observed on panicle weight in both seasons. In both seasons, NERICA 1 had significantly higher panicle length than other varieties, although not significantly different from WAB 56-104 in the late season. Significant interaction ($P < 0.05$) of AMF x variety was observed on panicle length in both seasons. In the early season WAB 56-104 had significantly higher panicle/m^2 than other varieties except NERICA 2 and NERICA 3. In the late season, NERICA 4 (59.50) had significantly higher panicle/m^2 than other varieties. Significant interaction ($P < 0.05$) of AMF x variety on number of panicle/m^2 was only observed in the late season. There was a significant ($P > 0.05$) varietal variability on grain weight/panicle in the early season with NERICA 3 (148.70) having significantly higher grain weight/panicle, with Moroberekan recording the least (104.20), while in the late season there was no significant differences among the varieties except NERICA 2 (54.70), having the least grain weight/panicle. Significant interaction of AMF x variety was observed on grain weight/ panicle in both seasons.

Table 4. Effect of AMF inoculation on development parameters, yield component and yield of upland rice varieties, early cropping season (2012)

Treatments	Days to 50% flowering	Days to 95% maturity	Panicle length (cm)	Panicle weight (g)	Panicles/m^2	Seeds/panicle	100 seed weight (g)	Yield (kg/ha)
Mycorrhiza(M)								
Without	85.17a	108.67a	16.64b	2.82b	75.1b	110.5b	2.63b	825b
With	75.56b	96.72b	20.75a	3.44a	128a	139.1a	3.33a	2484a
SE±	0.48	0.67	0.45	0.07	4.44	2.31	0.06	70.4
Varieties (V)								
NERICA® 1	74.17b	96.3b	20.38a	3.49a	97.3b	123.5	3.40a	1718
NERICA® 2	74.67b	95.7b	19.2ab	2.95b	115a	118.7	3.37a	1680
NERICA® 3	73.83b	95.7b	17.3c	3.38a	115a	148.7	3.25a	1876
NERICA® 4	74b	94.8b	19.42ab	2.88b	102.5ab	132.2	2.78b	1869
Moroberekan	111.76a	137.8a	17.9bc	3.00b	61.7c	104.2	2.70b	857
WAB 56-104	73.83b	95.8b	17.68bc	3.07b	117.8a	121.5	2.38c	1929
SE±	0.84	1.16	0.77	0.13	7.69	4.01	0.11	121.9
M*V	*	*	*	*	ns	*	ns	ns

For each variable, means followed by the same letter in the column are not significantly different by DMRT test.

Table 5. Effect of AMF inoculation on growth parameters of upland rice varieties, late cropping season (2012)

Treatments	Plant height (cm)			Number of tillers			Dry weight (g)		
	4 WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP	4 WAP	8 WAP	12 WAP
Mycorrhiza(M)									
Without	30.39b	54.04b	69.89b	2.28	2.56b	2.28b	0.44	0.82a	2.15b
With	35.11a	62.43a	83.26a	2.67	3.39a	3.00a	0.57	1.23a	2.89a
SE±	0.72	0.97	1.40	0.15	0.12	0.15	0.06	0.06	0.09
Varieties (V)									
NERICA® 1	38.32b	72.39b	92.24b	2.83a	3.50a	3.17a	0.63a	1.29ab	3.11a
NERICA® 2	38.06b	65.45c	88.25b	3.17a	3.83a	3.67a	0.61a	1.15ab	3.03a
NERICA® 3	39.02b	64.57b	88.29b	3.00a	3.50a	3.00a	0.53a	1.09b	2.83a
NERICA® 4	38.65b	67.31c	92.99ab	2.83a	3.50a	2.83a	0.53a	1.25ab	3.14a
Moroberekan	0.00c	0.00d	0.00c	0.00b	0.00b	0.00b	0.00b	0.00c	0.00b
WAB 56-104	42.47a	79.67a	97.67a	3.00a	3.50a	3.17a	0.73a	1.35a	2.99a
SE±	1.24	1.68	2.43	0.26	0.21	0.26	0.10	0.10	0.16
M*V	*	*	*	*	*	*	ns	*	*

For each variable, means followed by the same letter in the column are not significantly different by DMRT test.

Moroberekan (111.76 days) took significantly longer days- to- 50% flowering in the early season compared to other varieties. In the late season, WAB 56-104 (79.00 days) had significantly longer days-to-50% flowering, which was not significantly different from NERICA 4 (78.33 days). Significant interaction ($P < 0.05$) of AMF x variety was observed on days- to- 50% flowering in both seasons. Significant effect ($P < 0.05$) of variety was observed on days- to- 95% maturity in the early season, with similar pattern as observed on days- to- 50% flowering in the both seasons.

NERICA 1 (3.40 g) had significantly higher 100 seed weight than other varieties except NERICA 2 and NERICA 3. Similar pattern was also observed in the late season, with the exception that the least significant 100 seed weight was Moroberekan. Significant interaction of AMF x variety was only observed in the late season.

There was no significant varietal variability on grain yield/ha in the early season and late seasons. Since in the late season, Moroberekan did not emerge.

4. Discussion

The prospect of double cropping of upland rice in the rainforest transitory zone of Nigeria in meeting food security challenges could be resolved with the optimum availability of growth factors, especially water. This trial sought to explicate the effect of the application of AMF on some earlier screened drought tolerant varieties of NERICA rice to moisture stress. Earlier report by Dare, Abaidoo, Fagbola, & Asiedu (2012) had indicated low spore abundance and specie richness of AMF in the transitory agro-ecology of Nigeria, which necessitated the application of AMF inoculum. The trial indicated that in both seasons application of AMF resulted in comparatively better growth responses. Increase in the number of tillers would have resulted in increased assimilatory surface towards the interception of radiant energy. With higher plant height, there would have been a better canopy architecture for the interception of both direct and diffuse radiant energy for carbon assimilation, which was reflected in increased accumulation of dry matter in AMF treated rice plants. Earlier studies had further indicated that the presence of AMF had positive effect on crop growth, especially in water and nutrient limited conditions (Solaiman & Hirata, 1997). It was reported that AMF effect was observed through the accumulation of compatible osmolite (proline and sugar), resulting in the improvement of plant-water status (Auge, 2001). Other effects observed was efficient use of water through avoidance mechanism in moisture limited environment with increased surface-to-volume ratio facilitated by increased hyphal growth (Kothari et al., 1990). Earliness observed in both seasons could be suggested to be an induced phenotypic response (spatial avoidance mechanism) with limiting environmental factor, especially in the late season (Table 6). But this reason could not be adduced to the early season, since moisture stress could not be ascribed as a limiting growth factor.

Rainfall distribution pattern in this agro-ecological zone is bimodal and in the early growing season, there is always ample moisture to support crop growth, however, its erratic distribution could not preclude the advent of moisture stress (Table 1). The earlier positive phenotypic responses (growth and development) of upland rice varieties to AMF treatment was reflected on the yield and yield components, suggesting effective partitioning of the assimilates for AMF treated upland rice in both seasons. This could be ascribed to the ameliorative effects of AMF on rice (osmoregulatory, osmoprotective) (Ruiz-Lozano, 2003; Ruiz-Lozano et al., 1996) and the soil (nutrient availability) (Table 2). Nutrient availability in the presence of AMF application was also reported by Solaiman and Hirata (1997).

Table 6. Effect of AMF inoculation on development parameters, yield component and yield of upland rice varieties, late cropping season (2012)

Treatments	Days to 50% flowering	Days to 95% maturity	Panicle length (cm)	Panicle weight (g)	Panicles/m^2	Seeds/panicle	100 seed weight (g)	Yield (kg/ha)
Mycorrhiza(M)								
Without	74.50	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b
With	53.5	71.67a	16.39a	2.79a	91.33a	104.8a	2.91a	1586a
SE±	0.66	0.32	0.12	0.02	0.88	2.71	0.04	19.91
Varieties (V)								
NERICA® 1	75.33b	42.5b	10.07a	1.74a	51.33c	70.3a	183a	889b
NERICA® 2	75.83b	43.17b	9.8ab	1.65bc	55.17b	54.7b	1.82ab	944b
NERICA® 3	78.33a	42.17b	9.63ab	1.63c	52.5bc	63.2a	1.77abc	919b
NERICA® 4	75.5b	42.00b	9.58b	1.64c	59.5a	58.2a	1.66bc	1050a
Moroberekan	0.00c	0.00c	0.00c	0.00d	0.00d	0.00c	0.00d	0c
WAB 56-104	79.00a	45.17a	10.08a	1.71ab	55.5b	68.0a	1.65c	957b
SE±	1.15	0.55	0.20	0.03	1.53	4.70	0.07	34.48
M*V	*	*	*	*	*	*	*	*

For each variable, means followed by the same letter in the column are not significantly different by DMRT test.

Varietal variability with respect to growth, development and yield was observed both seasons. Comparatively better growth (accumulation of dry matter at 12 WAP) and development of Moroberekan in the first season could not be translated to better yield. This would have implied that the variety partitioned more of assimilates to the vegetative structure at the expense of reproductive growth, despite the longer period spent by the variety to utilise the available resources (higher crop growth duration). The non-emergence of Moroberekan in the late season could not be conclusively ascertained. It would be range from its genotypic specificity to poor environmental factors. Comparatively better performance of NERICA 4 could be ascribed to the positive influence of AMF inoculum on rhizosphere for better water and nutrient uptake. Most NERICA rice is reported to be low input in nature capable of withstanding stressful environmental factor (Matsunami, 2009). However, improved growth and development of WAB 56-104 could not translate to a higher yield, though with comparative yield as other NERICA rice varieties with the exception of NERICA 4.

This investigation was limited by the unavailability of nutrient uptake parameters (macro and micro nutrients) to ascertain how upland rice varieties responded to the availability of those nutrients in the soil. Also, a definitive conclusion would not be made in the absence of socio-economic assessment of the application of bio-fertiliser (AMF) in the rainforest transitory zone of Nigeria with respect to conventional practise of nutrient management (application of inorganic fertiliser). Further studies needed to be conducted to gauge the economic efficiency of the application of AMF in upland rice production in the rainforest transitory zone of Nigeria.

5. Conclusion

In both seasons, application of AMF resulted in comparatively better performance (growth, development and yield) in all the upland rice varieties investigated. Genotypic variability was observed in each and both seasons.

In the early season Moroberekan recorded better growth, which did not translate to a higher yield. However, late season recorded significant varietal variability with the application of AMF. Moroberekan expressed a significant depression in growth, development and yield, while NERICA 4 rice had higher yield in the presence of AMF. This could be attributed to its constitutive response to improved chemical properties of the soil (availability of macro and micro nutrients) in the presence of AMF.

6. Recommendations

NERICA 4 among other investigated NERICA rice varieties responded better to the application in the rainforest transitory zone of Nigeria, hence it could be recommended to farmers. This technology could serve as a low input technique in the quest for sustainable crop production system.

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