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Title

Influence of Legume/rice Sequence and Nitrogen on NERICA rice in Rainfed Upland and Lowland Ecologies of West Africa

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INTRODUCTION

The sustainability of crop production in West Africa is often severely limited by the rapid loss of soil productivity after only a few years of cultivation. Nutrients are commonly removed from the soil through crop absorption, leaching losses, erosion or immobilization. There is broad agreement that given the low fertility status of most West African soils such nutrient losses need to be replenished to maintain good tilth and soil organic matter.

However, most smallholder farmers have limited resources to purchase fertilizers. Therefore, exploring management strategies to use low inorganic N combined with the use of suitable grain legumes could help to sustain crop productivity. In this context it is surprising how little is known about the contribution of grain legumes to crop production by subsistence farmers in Africa (Mapfumo and Friller, 2001; Twomlow, 2004) even if N -fixing legumes have been repeatedly shown to have positive impact on soil fertility by enhancing N availability, reducing nematodes and P availability and uptake in cereal crops grown in the subsequent season (Bagayoko et al., 2000; Sanginga, 2003).

In an effort to solve the multifaceted problem of food shortage, breeding efforts have been made to develop crop varieties with higher yield potentials. Rice is the third most widely consumed food crop worldwide after maize (*Zea mays* L.) and wheat (*Triticum* spp.). In West Africa, rice is grown under both upland and lowland conditions and about 100 million people depend on it for their livelihoods (Nwanze et al., 2006).

Although world average yields of rice vary widely from 4.9, 2.3, 1.5 and 1.2 t ha^{-1} for irrigated, rainfed lowland, flood plain and uplands respectively, in West Africa, average yields are with 3.0, 2.1, 1.3 and 1.0 t ha^{-1} for irrigated, rainfed lowland, flood plains, and upland rice much lower (IRRI, 1993). The problems limiting local rice production include poor plant nutrition, low productivity of local varieties, pest and diseases (Fagade, 2000; Oikeh et al., 2008a).

New Rice for Africa (NERICA®) varieties are low-input rice germplasm developed for resource-limited, smallholder production systems (Dingkuhn et al., 1998) from interspecific crosses between high yielding *Oryza sativa* (Asian rice) and low-yielding resilient *Oryza glaberrima* (African rice; Jones et al. 1997). In Participatory Varietal Selection (PVS) trials, it was observed that NERICA produced substantial stable yields even under zero-N (Okeleye et al., 2003; Ariyo et al., 2004). While information on the nutrient requirements of upland NERICA exists (Rodenburg et al., 2006; Oikeh et al., 2008a), data on fertilizer recommendations for the NERICAs in rainfed upland and lowland ecologies of the West African savannas are lacking.

Nitrogen recommendations for rainfed lowland *O. sativa* varieties range between 40 and 70 kg N ha^{-1} for tall and short varieties, respectively (Enwezor et al., 1989). For rainfed upland varieties, recommendations are 40 kg N ha^{-1} and 120 kg N ha^{-1} for tall and short varieties, respectively (Imeokperia et al., 1992; Imeokperia and Okusanya, 1997). But studies on the use of different agricultural inputs by farmers in northern Nigeria showed that most farmers applied low rates of inorganic fertilizers, on average 40 kg N ha^{-1} (Manyong et al., 2001). For both rice ecologies there is an urgent need to harmonize the use of organic and inorganic fertilizer sources to sustain rice yields over longer periods of time while preserving soil productivity (Ncube et al., 2007). In this context the objectives of this study was to determine the effect of preceding grain legume crops combined with inorganic N on yields of upland and lowland NERICAs in the West African savannas.

MATERIALS AND METHODS

NERICA varieties developed for rainfed upland and lowland ecologies by the Africa Rice Center (WARDA) were screened for their responses to N and phosphorus (P) application in 2006 and 2007. From these trials, the most fertilizer responsive NERICAs selected and used for on-farm trials in legume/rice rotation experiments in 2007 and 2008.

Location and time of studies

Rainfed upland rice

On-farm field experiments were conducted in 2007 and 2008 in Kasuwa Mangani village near Kaduna (10°24'N, 7°42'E) in the northern Guinea savanna (NGS) of Nigeria with an unimodally distributed annual rainfall of 1140 mm. The soil at the selected three experimental sites was classified as a Typic Haplusalf (Kowal and Knabe 1972). Chemical analyses of the topsoil (0-30 cm) showed a pH (H_2O) of 4.5, total organic carbon of 7.9 g kg^{-1}, total N of 0.9 g kg^{-1}, Mehlich's available P concentration of 1.96 mg kg^{-1}, exchangeable K of 0.10 mol$_c$ kg^{-1}, exchangeable Mg of 10.73 mol$_c$ kg^{-1} and Ca of 1.55 mol$_c$ kg^{-1}. The soil texture consisted of 537 g kg^{-1} sand, 163 g kg^{-1} silt and 300 g kg^{-1} clay (IITA 1989). Prior to the onset of the experiments the sites had been under fallow for about six years given their low productivity.

Rainfed lowland rice

The rainfed lowland experiment was conducted in 2007 and 2008 at the Africa Rice Center (WARDA) fields within the Research farm of the National Cereals Research Institute at Edozhigi (09O 45′N, 06O 7′E, 70.5 m elevation) southern Guinea savanna [SGS]), Bida, Nigeria. Rainfall was unimodal. The three selected experimental sites were waterlogged acid soil with pH (H2O) 4.6 and classified as Typic Haplusalf (Kowal and Knabe, 1972). Average chemical analysis of top soil (0 – 30 cm) indicated organic carbon of 7.8 g kg-1, total N of 0.7 g kg-1, Mehlich III-available P of 1.98 mg kg-1, exchangeable Mg of 0.29 molc kg-1, and Ca of 1.26 molc kg-1, and Fe of 28.56 mg kg-1. Soil textural analysis indicated sand 540 g kg-1, silt of 280 g kg-1 and clay of 180 g kg-1 (IITA 1989). The fields were under fallow for about three years before the trials.

Treatments

The six treatments consisted of (i) IT 98K-131-2 (a dual purpose cowpea (*Vigna unguiculate* (L) Walp), (ii) IT 93K-52-1 (a grain cowpea), (iii) TGx 1844-18E (a dual purpose soybean, (iv) TGx 1485-1D (a grain soybean), (v) Mucuna (*Mucuna utilis* L) and)vi) use of a fallow (without legumes).

In the NGS the legumes were sown in October 2007, while in the SGS, they were seeded in November 2007. The grains were harvested upon maturity by removing the pods, but the stover was incorporated *in situ* immediately after harvesting. In 2008, the selected rice varieties were planted in each of the two agroecologies on the legume incorporation plots and on fallow (control) plots.

The NERICA cultivar selected for the uplands (NGS) was NERICA 14, and Yar China (local check), while NERICA L-42 and an Edozhigi variety (local check) were used in the lowlands (SGS).

Experimental design

The experiment was laid out as a Randomized Complete Block design with a split-split plot arrangement at each of the sites which served as a replication. The main-plot factor was grain legumes of which the stover was incorporated in 2007. The sub-plot factor was N application at two levels (0 and 30 kg N ha^{-1}). Basal P and K were applied at the rate of 13 kg P ha^{-1} as triple superphosphate (20% P) and 25 kg K ha^{-1} as muriate of potash (KCl, 60 % K_2O) were given to all plots except for the control plots. The N was applied topdressed in two splits with one-half at 21 days after sowing (DAS) and the remaining half at about panicle initiation (45-50 DAS). The sub-sub-plot comprised two rice cultivars. The main plot size was 5 × 21 m (105 m2) while the sub-subplot size was 3 × 5 m (15m2).

In the rainfed lowlands seedlings were transplanted at 3 seedlings stand^{-1} at 20 × 20 cm on flats that were later bunded. The bunds were maintained throughout the study period to retain water in the plots needed for lowland rice production. The upland rice plots were seeded directly by dibbling 5-7 seeds per hole at 20 × 20 cm spacing and later thinned to four seedlings per stand to yield a plant density of 1×10^6 plants ha^{-1} (Oikeh et al. 2009). All plots were weeded manually by hoeing just before top dressing of N fertilizer.

Sampling and measurements

Recorded was the number of tillers and the number of days to 50% flowering and to 80% maturity. Yield data included total dry matter (TDM), harvest index, number of panicles m^{-2}, 1000-grain weight, and grain yield corrected to a 140 g kg^{-1} moisture basis.

Statistical analysis

All data collected were subjected to analysis of variance using the mixed model procedure within the restricted maximum likelihood method (REML) for variance estimates in SAS (SAS Institute, 2001) separately for each rice ecology. Fixed effects were previous crops, N and cultivars, while sites (replications) were random effects. Mean separation was performed using the SAS least square means test (PDIFF) at $P \leq 0.05$.

The advantages of the combined use of legume rotation and applied urea-N on rice grain yields were calculated using the following equation (Vanlauwe et al., 2001):

Added benefits (t ha^{-1}) = $Y_{comb} - (Y_{30N} - Y_{0N}) - (Y_{rot} - Y_{0N}) - Y_{0N}$

Where:

Y_{comb} was the rice yield in legume rotation plus 30 kg N ha^{-1} as urea (t ha^{-1}),
Y_{30N} was rice yield in 30 kg N ha^{-1} as urea (t ha^{-1}),
Y_{0N} was rice yield in 0 kg N ha^{-1} as urea (t ha^{-1}),
Y_{rot} was rice yield in legume rotation without urea (t ha^{-1}).

RESULTS AND DISCUSSION

Rainfed upland rice

Yield and yield components

Grain yield was not significantly affected by preceding legume, inorganic N, cultivar, and their interactions (Table 1). Rice yields ranged from 0.6-0.8 t ha^{-1}. However, the farmers' rice had significantly higher TDM (1.7 t ha^{-1}) than NERICA 14 (1.2 t ha^{-1}). Although not significant, the preceding soybean and mucuna plots gave 33% higher grain yields than the previous fallow control plots (Table 2). The previous dual-purpose soybean plots yielded with 1.9 t ha^{-1} the highest TDM (Fig. 3), while the previous grain-soybean plots yielded with about 50% the highest HI (Table 2).

The treatments in this study involved the use of N-fixing dual-purpose / grain soybean and cowpea, limited use of inorganic N and a resilient rice variety to enhance rice productivity on the highly degraded soil. Incorporating mucuna and soybean (dual-purpose or grain) before sowing rice increased grain yield by > 30% compared to the control and ranked among the highest in added benefits (0.8–0.9 t ha^{-1} grain yield). A similar advantage of mucuna had earlier been reported in mucuna-maize rotation systems by Casky et al., (1998) and in soybean-upland rice systems by Oikeh et al. (2008b). The yields of rice following soybean rotation in the current study in which the residues were incorporated after harvest were much lower than the yields reported in the earlier study of Oikeh et al. (2008b). In this experiment the residues were exported from farmers' fields in the NGS of Benin. Our results might be explained by the highly degraded and acidic nature of the site used that had been left under fallow by farmers for about six years due to low productivity. They suggest that the level of N used to supplement organic N source in this highly degraded soil would likely need to be higher in order to achieve a significant yield increase. A much longer rotation would be needed to reclaim the productivity of this soil.

Integrating mucuna and soybean into legume-rice systems could play a significant role in the smothering of weeds. Weed control in upland rice production contributes significant investment to smallholder farmers in West Africa (Ekeleme et al 2009).

The Harvest index (HI) is an inherent ability of varieties to partition assimilates to the sink (grains). Incorporating grain-soybean before sowing rice in this study appeared to increase the HI by 16% compared to the control; possibly previous grain-soybean enhanced the release of nutrients that was utilized by the varieties more efficiently to influence this trait in our study.

Oikeh et al. (1998) and Vanlauwe et al. (2001) reported that farmers in the NGS are often reluctant to grow legume crops such as mucuna that will not provide them with direct food value or monetary benefit in spite of the benefits in weed control and replenishment of soil nutrients. Therefore, farmers need to be convinced about the indirect contribution of growing mucuna to enhance rice productivity.

Van Noordwijk et al. (1995) estimated mucuna-N made available to a subsequent crop at 83%. This could have been the reason why mucuna plots preceding rice provided the highest (33%) rice yields in this study. Adigbo and Okeleye (2006) also reported that mucuna incorporation enhanced upland rice yield as observed in this trial. It has been suggested that since farmers are very reluctant to devote their land solely to legume cover crops that would not provide food value for human consumption (Becker and Johnson 1998, 1999) although there is impact on restoring soil fertility (Oikeh et al. 1998; Vanlauwe et al. 2001), the use of dual-purpose soybean which has a high potential of covering the soil to suppress weed and conserve the soil.

Rainfed lowland rice

Physiological traits of lowland rice

Application of 30 kg inorganic N enhanced the number of tillers by 10% only at 21 days after transplanting (DAT) compared to zero-N (Table 3). Our results are in agreement with previous studies which reported a significant effect of N on tiller number and plant height in upland rice with application of inorganic-N compared with zero-N (Adigbo and Okeleye, 2006; Oikeh et al., 2008a).

Leaf area index at mid-tillering (21 DAT) and flowering (21 DAT), and number of tillers at flowering and maturity were significantly influenced by cultivar (Table 4). The farmers' variety had a 31% higher LAI at mid-tillering and flowering, but with 11–25% significantly lower tiller production than NERICA L– 42 at flowering and maturity (Table 4). NERICAs have been reported to have greater tillering ability than *O. sativa* varieties (Okeleye et al. 2006).

Grain yield and yield components

NERICA L–42 produced 28% significantly more panicles which had a 13% smaller ($P < 0.05$) grain size (determined through the thousand-grain weight) than the farmer's cultivar. Although not significant, the plots with previously incorporated grain soybean (cv. TG× 1485 – 1D) and dual-purpose cowpea (cv. IT 98K – 131 – 2) residues gave about 0.8 t ha^{-1} more rice yield than plots with previous mucuna or dual-purpose soybean (Table 4). Consequently, the integration of these cultivars of soybean and cowpea in lowland rice-based systems might enhance lowland rice productivity.

Despite the difference in LAI and panicle production between the rice cultivars, their grain yields were similar (3.6 t ha^{-1}). This might have been due to iron toxicity encountered on the experimental sites which affected both cultivars, thus limiting their potential productivity.

CONCLUSIONS

Smallholder farmers commonly harvest their legumes and export them from the fields; and they are reluctant to grow sole mucuna. This study has shown that the incorporation of legume residues back into the soil immediately after harvest with an addition of 30 kg N to the succeeding rice crop in rotation may enhance rice yields in both rainfed upland and lowland agroecologies. However, for the highly degraded acidic upland soils similar to the site used in this study, the succeeding upland rice will benefit from a higher rate of inorganic N than the 30 kg ha^{-1} and a longer rotation to restore the productivity of the soil. Further studies are needed to examine how to best integrate appropriate legumes tolerant to iron toxicity and iron-toxicity tolerant NERICA varieties into rainfed lowlands in order to enhance their rice productivity.

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