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Tillage, Rice Straw Mulch and Nitrogen Fertilization Effects on Upland Rice Yield in Northern Benin

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Abstract
In Benin, upland rice is typically grown under intensive tillage in slash-and-burn systems. Some of the major constraints associated with upland rice production are water deficit, declining soil fertility and rice yield. To explore effective ways to improve rice yield, field experiments were conducted on two upland rice soils (Lixisol and Gleyic Luvisol) in northern Benin, West Africa for two consecutive years. The treatments comprised two tillage systems (no-tillage, and manual tillage), two rice straw managements (no rice straw, and rice straw mulch at 3 Mg ha^{-1}) and three nitrogen fertilizer levels (no nitrogen, moderate level of nitrogen: 60 kg ha^{-1}, and high level of nitrogen: 120 kg ha^{-1}). Phosphorus and potassium fertilizers were applied to be non-limiting at 40 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1}. Four replications of the twelve treatment combinations were arranged in a randomized complete block design. Soil moisture and soil temperature were measured at 5 cm depth in 6 to 10 days intervals during the growing seasons. At maturity, crop parameters measured included rice grain yield, aboveground biomass, and root biomass. No-tillage with rice straw mulch increased soil moisture and decreased soil temperature. Root biomass, shoot biomass and rice yield significantly increased with rice straw mulch and nitrogen fertilizer application. The highest response of rice yield to nitrogen fertilizer addition was obtained for 60 kg N ha^{-1} in combination with 3 Mg ha^{-1} of rice straw for the two tillage systems. No-tillage combined with rice straw mulch and 60 kg N ha^{-1} could be used by smallholder farmers to improve soil water availability and upland rice yield in northern Benin.
Keywords: management practices, soil moisture, soil temperature, upland rice, yield.

1. Introduction

Rice plays a critical role in contributing to food security, income generation, poverty alleviation and socioeconomic growth in many West African countries (Diagne et al. 2013). In most of these countries, the rice production is far below the rice demand (Seck et al., 2013). In Benin, the rice self-sufficiency rate is about 26%, resulting in the need for annual imports to meet the growing rice demand (Index-Mundi, 2015). Given the large amount of rice that Benin currently buys on the international market (e.g., 350,000 metric tons were imported in 2014); an increase in local rice production is of great importance for increasing food security.

In Benin, rice is produced mainly under rainfed conditions. There are two main ecosystems of rice known as upland and lowland rice. Upland rice, also known as aerobic rice, is generally grown in non-flooded, well drained soils on level to steeply sloping fields. Lowland rice, also known as paddy rice, is generally grown on soils that are flooded or irrigated (Andriesse and Fresco, 1991). The yield of upland rice is much lower than the yield of lowland rice. The main factors which are responsible for the lower upland rice yield are water deficit and use of low inputs by the farmers (Haefele et al., 2013).These inputs mainly include fertilizers, insecticides, and herbicides. Use of low inputs is associated with drought risk and poverty. Despite the lower yield, upland rice plays an important role in Benin due to low production cost and lack of drainage and irrigation facilities in the lowlands (Totin et al., 2014). Rainfed upland rice ecosystems account for about 27% of the total rice area of the country and are used by 28% of the rice farmers (Diagne et al. 2013).

Among the essential plant nutrients, nitrogen is one of the most yield limiting nutrients for upland rice production (Fageria et al., 2010). The nitrogen deficiency in upland rice in Benin is related to low organic matter content of rice growing soils, use of low level of nitrogen fertilizers by farmers due to high cost of these fertilizers (Koné et al., 2011). Nitrogen deficiency is also related to low nitrogen use efficiency by the rice crop due to loss by leaching, volatilization, nitrification and/or denitrification and erosion (Worou et al., 2012). Hence, the use of integrated approach to maximize on-farm nutrient cycling and to build or maintain soil fertility and crop productivity can be an important strategy in improving the nitrogen use efficiency on upland rice soils.

The management of rice straw and its impact on nutrient cycling and soil fertility are important issues to the sustainability of rice production systems. In Benin, farmers either remove straw from their fields for cattle feed or burn in situ (Totin et al., 2013). Straw burning is especially popular in rice production systems in the country because of its advantages in pest and disease control and saving of labor and energy for the subsequent land preparation (Rodenburg and Johnson, 2009). However, estimated losses are up to 80% of nitrogen, 25% of phosphorus, 21% of potassium and 4-60% of sulphur in addition to the problem of air pollution (Gangwar et al., 2006). One possible solution would be to use rice straw as a soil mulch material in upland rice production systems. However, the effect of rice straw mulch on crop yield and nitrogen use efficiency is inconclusive and has been shown to vary with the characteristics of the site and the climate (Erenstein, 2002). Experiences so far have highlighted positive, neutral and negative short-term yield responses to rice straw mulch. For example, rice straw mulch increased soil moisture and upland rice yields at Bamè in southern Benin (Totin et al., 2013). In contrast, Wang et al. (2001) reported that application of cereal straw with wide C:N ratio such as rice or wheat straw led to soil nitrogen immobilization and inhibited rice growth at early stages with a subsequent decline in rice yield. Gangwar et al. (2006) found that higher levels of nitrogen were required to crops sown under rice straw mulch while Rahman et al. (2005) found that lower levels of nitrogen were required. However, the reports on the effect of rice straw mulch on crop yield and nitrogen use efficiency are not consistent; therefore, further study is required to assess the effect of rice straw mulching on crop yield and nitrogen use efficiency.

Introducing no-tillage management may also contribute to improving upland rice productivity and to reducing fuel, animal or human energy required for land preparation in Benin where tillage has been the common practice for crop production (Saito et al., 2010). Various studies have shown the effect of no-tillage on soil moisture, soil organic matter (Šimon et al., 2009), crop nitrogen uptake and crop performance (Malhi and Lemke, 2007; Malhi et al., 2006). When practiced over a long period of time, no-tillage can measurably enhance the quantity and quality of soil organic matter (SOM) in the soil surface layer (Šimon et al., 2009), thereby enhancing the nutrient supplying capacity of a soil by increasing readily mineralizable organic nutrient levels (Van Den Bossche et al., 2009). Thus, no-tillage has been shown to achieve higher grain yields than conventional tillage with the same level of nitrogen (Šíp et al., 2009). However, other studies have found that no-tillage may require greater nitrogen fertilization input to achieve the same grain yield as conventional tillage due to low nitrogen mineralization in wetter soils (Vetsch and Randall, 2000). The large variation in grain yield and nitrogen use efficiency suggests that the effect of no-tillage depends on the soil type and climatic conditions.

Much of the research on the effects of tillage systems, straw management and nitrogen fertilizer on crop productivity and nitrogen use efficiency has been conducted in temperate ecosystem (Malhi and Lemke, 2007; Malhi et al., 2006), but remains very rare in the Savannah agro-ecological zone in West Africa (Ouédraogo et al., 2006). Assessing the effects of these management practices on upland rice yield and nitrogen use efficiency in Benin will provide information on the pathway through which they affect crop yield in the Savannah agro-ecological zone in West Africa. Such study will also help to suggest alternative farming strategies to the upland rice farmers. The objectives of this study were to (1) identify the effects of tillage systems, rice straw mulching and nitrogen application on upland rice yield, (2) determine the optimum level of nitrogen fertilizer to increase rice yield under various tillage systems and rice straw mulching, and (3) suggest an optimum combination of factors for efficient management practices to increase upland rice yield.

2. Material and methods

2.1 Experimental sites

The study was conducted on two upland rice soils in the Tetonga catchment in northern Benin during the two rainy seasons of 2014 and 2015. The catchment is located between 1°01’ E and 1°14’ E and 10°42’ N and 10°57’ N and belongs to the Sudanian Savannah agro-ecological zone in West Africa (Fig. 1). In this area, the climate is semi-arid with one dry season (November-April) and one rainy season (May-October). The mean annual air temperature, precipitation and potential evapotranspiration are 27°C, 1177 and 1484 mm, respectively (data from 1985 to 2014). Mean precipitation in the rainy season is about 887 mm. The precipitation of the rainy season was below-normal in 2014 (830 mm) and above-normal in 2015 (935 mm). The two experimental fields were within 2 km of each other in a gently-sloping area with relative difference in elevation between the two fields of about 3 m. Site 1 was located at the upper part, and Site 2 was at the lower part of the toposequence (Fig. 1). According to FAO soil taxonomy, the soil at the upper slope was a Lixisol and at the lower slope a Gleyic Luvisol (Youssouf and Lawani, 2000).

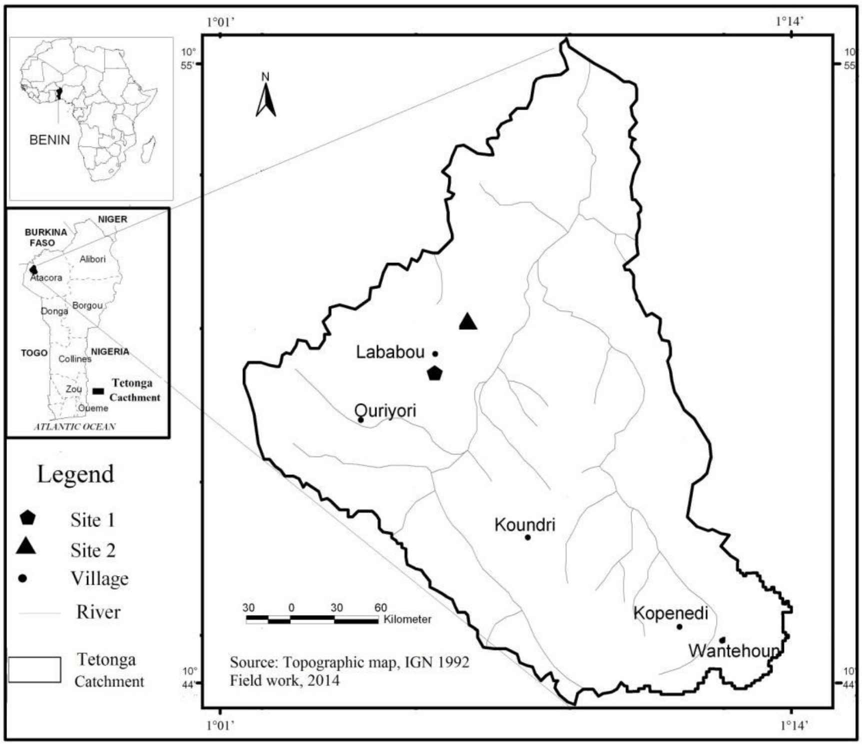

Fig. 1: Location of the experimental sites

Soil samples (0-20 cm soil layer) were collected before the onset of the experiment for particle size distribution, pH, soil organic carbon content, total nitrogen, extractable phosphorus and extractable potassium. The particle size distribution was determined based on the hydrometer method (Bouyoucos, 1951). The soil pH was determined using a soil-to-water ratio of 1 to 2.5. The soil organic carbon content was determined by chromic acid digestion and the total nitrogen by Kjeldahl digestion. The available phosphorus content of the soil was determined using the Bray-1 method (0.5 M HCl + 1 M NH_4F). The soil potassium was extracted with 1 M NH_4-acetate and the content was determined by flame emission spectrophotometry.

Soil of Site 1 was loamy, acidic (pH < 6.1) with low organic carbon content (< 0.5%), while soil of Site 2 was a clay loam, neutral (pH 6.6 – 7.3) with medium organic carbon content (1.2%). Both sites had low nitrogen (< 0.03%), medium phosphorus (10-20 ppm) and medium potassium (0.8-1.6%) content. The two experimental sites were previously in continuous rice cultivation under manual tillage, rice straw removal and no fertilizer application.

2.2 Experimental design and treatments

The experiment consisted of twelve treatment combinations, i.e., two levels of tillage, two levels of crop residue, and three levels of nitrogen (N) application. The two levels of tillage were no-tillage (T_0) and manual tillage (T_1). The two levels of crop residue were no-rice straw mulch (M_0) and rice straw mulch at 3 Mg ha^{-1} of dry rice straw (carbon content: 53.36%, nitrogen content: 0.65%, C:N ratio 82:1) (M_1). The three levels of nitrogen application were no nitrogen application (N_0); moderate level of nitrogen (60 kg N ha^{-1}) recommended by the extension services in north Benin (N_1); and high level of nitrogen (120 kg N ha^{-1}) (N_2). Phosphorus (P) and potassium (K) fertilizers were applied in all the experimental plots to be non-limiting at 40 kg P_2O_5 ha^{-1} and 40 kg K_2O ha^{-1}. Nitrogen, P and K were applied in the form of urea, triple superphosphate and muriate of potash, respectively. The full rate of P and K with 50% of the N was applied as basal fertilizer the day of sowing. 25% of the N was applied at the beginning of the tillering stage (about two weeks after germination) by top dressing. The last 25% of the N was applied at panicle initiation stage, also by top dressing. With a net plot size of 6 m x 5 m, four replications of the twelve treatment combinations were arranged in a randomized complete block design.

The no-tilled plots were treated with glyphosate to kill the fallow vegetation whereas the tilled plots were ploughed with hand hoes to the depth of 15-20 cm from the soil surface. The desired rates of rice straw were applied on the plots. The rice variety NERICA14 (WAB 880-1-32-1-2-P1-HB; *O. sativa x O. glaberrima* interspecific progeny) was sown on 19 July and 22 July in 2014 and 2015, respectively. Rice seeds were directly sown by hand using a dibbling stick at a row and plant-to-plant distance of 20 cm with four seeds per hill. Pre-emergence herbicide (CONDAX$^{©}$, 30% bensulfuron-methyl-W.P) was applied 24 hours after rice sowing. Two weeks after sowing, the rice plants were thinned to two plants per hill. Thereafter, weeds were hand-picked when it was necessary so as to keep the plots weed-free.

2.3 Measurement and data collection

Soil moisture and soil temperature were measured in the first 5 cm of soil in 6 to 10 days intervals during the growing season (June-November). Soil moisture was measured with a portable TDR probe (ML2x-KIT, Delta-T Devices Ltd., Cambrigde, UK). Soil temperature was measured with a hand-held soil thermometer (Omegaette HH303Type K J, OMEGAEngineering, Inc., Stamford, CT, USA). Soil moisture and soil temperature were measured at height points in the center of each plot. The means of the soil moisture and soil temperature from the eight points were used as central values of the plot.

At maturity, rice root was sampled using the monolith procedure (Shashidhar et al., 2012). Two monolith samplers (20 cm x 20 cm, 20 cm depth) were pounded into the soil in the harvested area of each plot with a sledgehammer until the top of the sampler was levelled with the soil. The soil was stored in labeled plastic bags. Roots were separated from the soil by flotation. The soil sample was transferred into a plastic container and mixed with more water. After mixing, the soil, water, and root mixture began to separate: soil settled at the bottom, large roots floated at the water surface and some roots, although not visible, floated below the water surface. Large, visible pieces of roots were picked out with forceps and transferred to a small container of clean water. To collect the small roots floating below the water surface, the liquid portion was poured onto a 1.0 mm sieve. These roots were transferred to the small container of clean water with roots. Water was again added to the plastic containing soil, and the liquid portion was poured onto the sieve to isolate the roots. This procedure was repeated until no more roots were collected on the sieve. After mixing the soil with water and capturing the roots on the sieve, the soil was visually examined for any remaining roots. All roots from the container were then poured onto the sieve and transferred to a small labeled plastic bag. Root samples were dried in an oven at 70 °C for 72 hours. A high-precision balance (milligram) was used to determine the dry weight of the roots.

At maturity, two replicates of 1 m^2 were harvested in the center of each plot by cutting the stalk directly on the soil surface. The samples were threshed to determine straw and grain yields. The dry weight of straw biomass was obtained after 72 h in the drying oven at 70 °C. Grain yields were reported at 14% moisture content. The shoot dry weight was defined as the dry weight of the entire aerial portion of rice plants and referred to the sum of the dry weight of straw biomass and grain yield (Fageria and Moreira, 2011).

The agronomic efficiency of nitrogen (AEN) was defined as the economic production obtained per unit of nitrogen applied (Fageria et al., 2010). It was used to evaluate optimal response of rice yield to nitrogen application under the various tillage systems and rice straw management. It was calculated according to Eq. (1).

$$AEN = \frac{(G_f - G_u)}{N_a} \quad (1)$$

AEN is the agronomic efficiency of nitrogen (kg kg^{-1}), G_f is the grain yield of the fertilized plot (kg ha^{-1}), G_u is the grain yield of the unfertilized plot (kg ha^{-1}), and N_a is the quantity of nitrogen applied (kg ha^{-1}).

2.4 Statistical analysis

All the statistical tests, models and figures were made with the R statistical software. An analysis of variance was performed on the treatments. Mean values were tested for significant differences by using a least significance difference (LSD). The probability level ≤ 0.05 was designated as significant.

3. Results

3.1 Soil moisture

Soil moisture fluctuated at both sites with rainfall events. Soil moisture was approximately twice as high in no-till treatments compared with tilled treatments from the day of tillage to the day of sowing (Fig. 2). After sowing and before rice harvest, a tillage and rice straw mulch interaction effect was observed for soil moisture. Soil moisture was lower in till and no straw treatments and higher in no-till plus straw treatments. From mid-October, a steady decrease in soil moisture was recorded in all treatments due to the end of the rainy season (Fig. 2). At both sites, average soil moisture during the growing seasons was in the order of no till + straw > no till, no straw > till + straw > till, no straw.

3.2 Soil temperature

Soil temperature slightly varied during the growing season (Fig. 3). Seasonal mean amplitudes of 11 °C and 13 °C were found during the growing seasons of 2014 and 2015, respectively. The lowest soil temperatures (24 °C in 2014 and 23 °C in 2015) were recorded at maximum rice tillering stage and panicle initiation. The highest soil temperatures were observed at the beginning and at the end of the rainy season (35 °C in 2014 and 36 °C in 2015). After rice harvest, soil temperature steadily increased. During the two growing seasons, there was a significant interaction effect of tillage and rice straw mulch on soil temperature. Soil temperature was lower under no-tillage + rice straw mulch (26 - 27 °C) and higher under no-tillage and no rice straw mulch (30 - 32 °C).

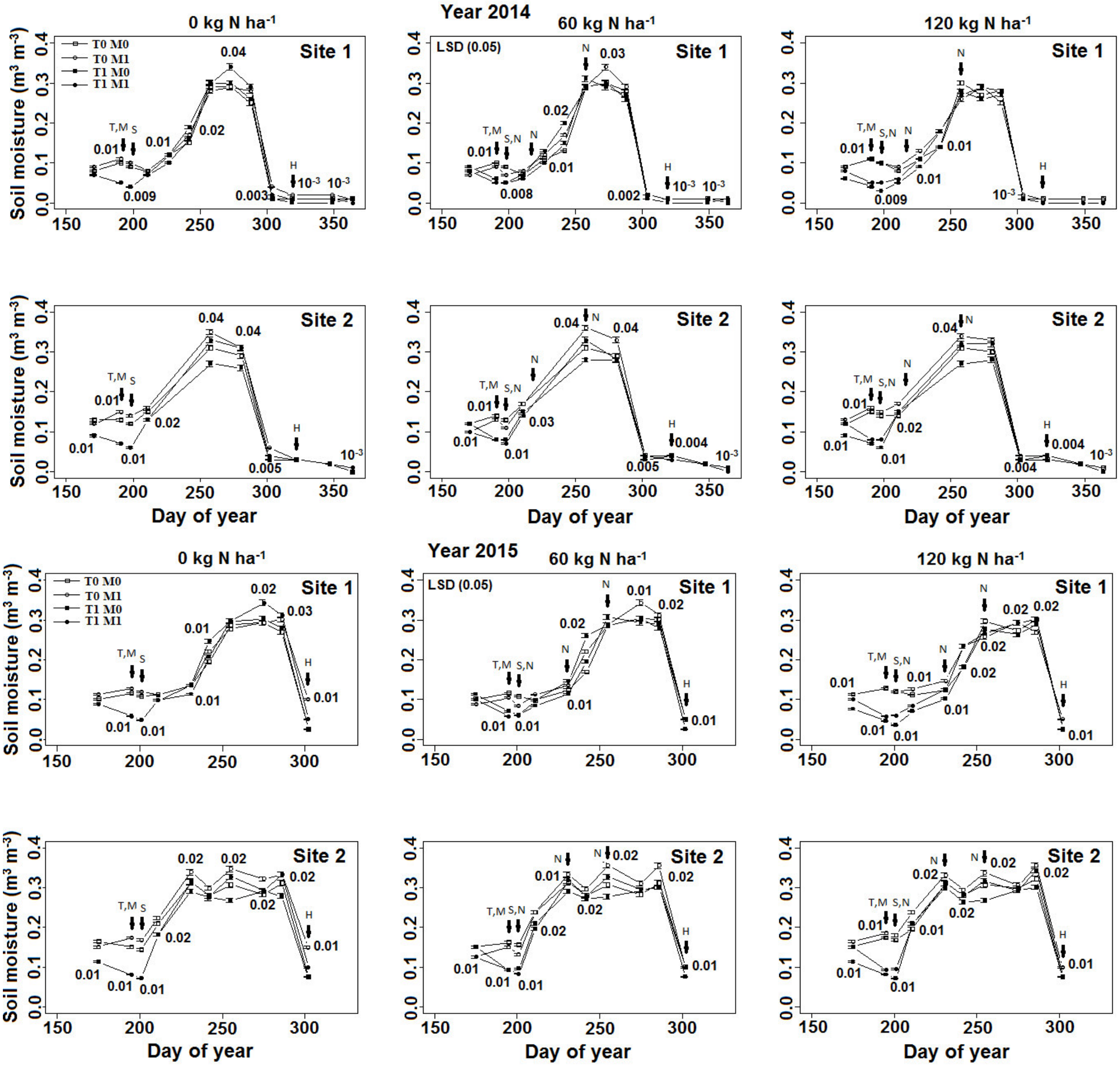

Fig. 2: Tillage and rice straw management effects on daily soil moisture at different nitrogen fertilization levels during the growing seasons of 2014 and 2015 at the experimental sites 1 and 2. T: tillage, M: application of rice straw mulch, S: direct sowing, N: nitrogen fertilizer application, H: harvest, T_0M_0: no-tillage, no straw mulch, T_0M_1: no-tillage, straw mulch, T_1M_0: manual tillage, no straw mulch, T_1M_1: manual tillage, straw mulch. LSD values for daily soil moisture at a specific sampling date indicate significant differences at $p \leq 0.05$ between combination of tillage and rice straw management; if no value is shown then the difference is not significant. The error bars represent the standard error.

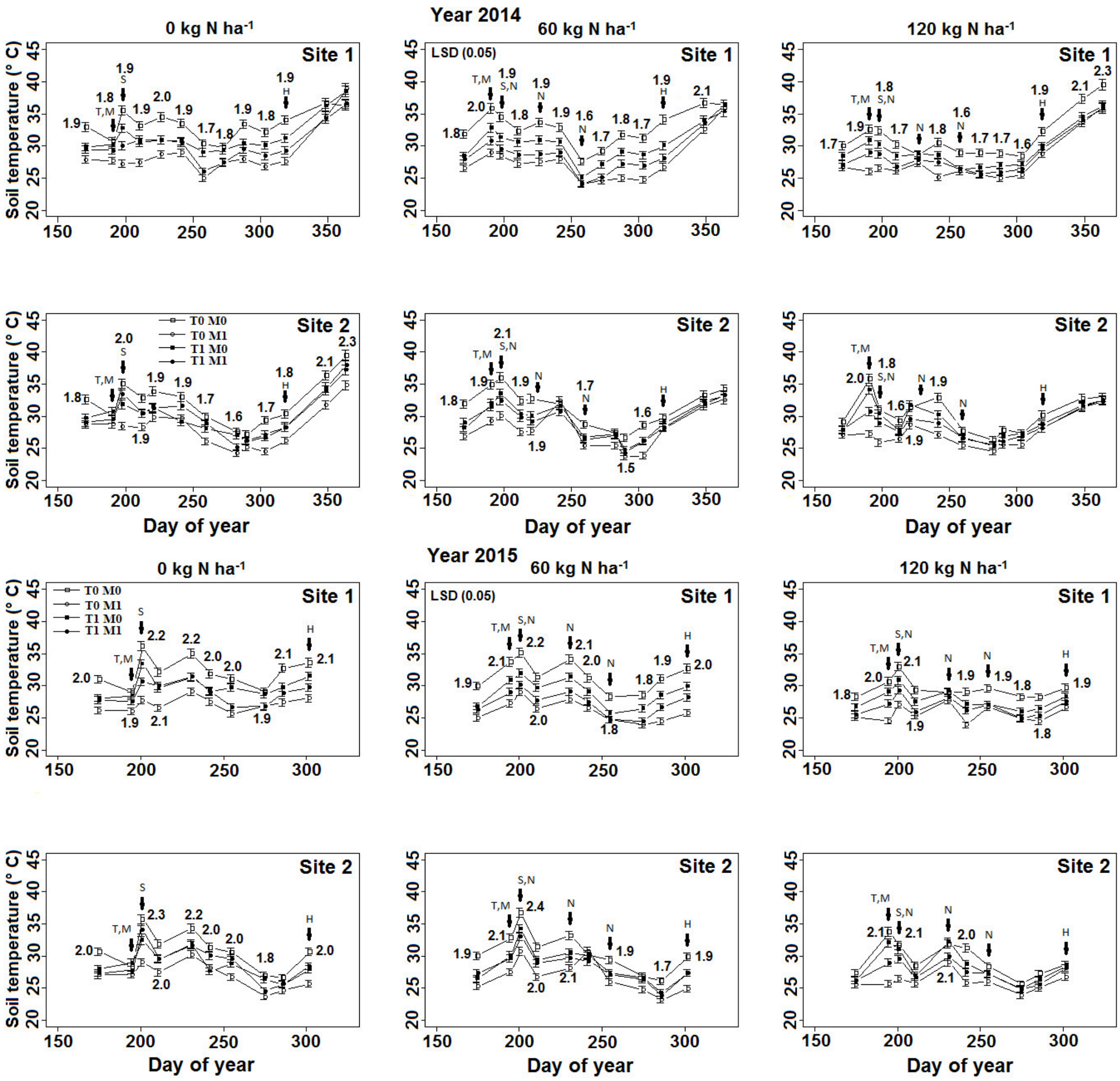

Fig. 3: Tillage and rice straw management effects on daily soil temperature at different nitrogen fertilization levels during the growing seasons of 2014 and 2015 at the experimental sites 1 and 2. T: tillage, M: application of rice straw mulch, S: direct sowing, N: nitrogen fertilizer application, H: harvest, T_0M_0: no-tillage, no straw mulch, T_0M_1: no-tillage, straw mulch, T_1M_0: manual tillage, no straw mulch, T_1M_1: manual tillage, straw mulch. LSD values for daily soil temperature at a specific sampling date indicate significant differences at $p \leq 0.05$ between combination of tillage and rice straw management; if no value is shown then the difference is not significant. The error bars represent the standard error.

3.3 Root biomass, shoot biomass and root to shoot ratio

Averaged over the two growing seasons, application of 3 Mg ha^{-1} of rice straw mulch increased root biomass, shoot biomass and root to shoot ratio of rice by 0.4 Mg ha^{-1}, 1.8 Mg ha^{-1} and 0.02, respectively compared with the non-straw mulch treatments (Table 1). The main effect of nitrogen levels on root biomass, shoot biomass and root to shoot ratio of rice was significant (Table 1). Without nitrogen application, root growth of rice was hindered as shown by the least root biomass under the zero-nitrogen fertilizer treatments (0.8-0.9 Mg ha^{-1}). Both root and shoot biomass increased with nitrogen levels but the root to shoot ratio decreased with nitrogen levels due to a smaller increase in root biomass with a greater increase in shoot biomass in response to increased N level (Table 1). There was a significant interaction effect of rice straw mulch and nitrogen fertilizer levels on the root biomass and shoot biomass of rice (Table 2). The increase in root biomass and shoot biomass with nitrogen levels was higher in straw mulch treatments compared with non-mulch treatments. Rice straw mulch and nitrogen fertilization had similar effects on root biomass and shoot biomass in the two tillage systems and at the two sites (Table 2).

Table 1: Effects of tillage systems, rice straw management and nitrogen levels on root biomass (RB), shoot biomass (SB), root to shoot ratio (RS) and grain yield (Yield) of rice during the growing seasons (July-November) of 2014 and 2015 evaluated at two experimental sites

Treatment	2014				2015			
	RB Mg ha^{-1}	SB Mg ha^{-1}	RS Mg Mg^{-1}	Yield Mg ha^{-1}	RB Mg ha^{-1}	SB Mg ha^{-1}	RS Mg Mg^{-1}	Yield Mg ha^{-1}
Site 1	0.8 a	6.2 a	0.14 a	2.7 a	1.0 a	7.3 a	0.14 a	2.9 a
Site 2	1.0 b	7.6 b	0.13 a	3.2 b	1.2 b	7.8 b	0.15 a	3.4 b
LSD (main site effect)	0.15	1.16	ns	0.6	0.10	0.40	ns	0.3
Tillage systems (T)								
No-tillage (T_0)	0.9 a	7.2 a	0.13 a	3.0 a	1.1 a	7.4 a	0.15 a	3.2 a
Manual tillage (T_1)	0.9 a	6.6 a	0.13 a	2.9 a	1.1 a	7.7 a	0.15 a	3.0 a
LSD (main T effect)	ns	ns	ns	ns	ns	ns	ns	ns
Rice straw (M)								
No straw	0.8 a	6.5 a	0.12 a	2.6 a	0.9 a	6.9 a	0.14 a	2.6 a
3 Mg ha^{-1} of straw	1.0 b	7.3 b	0.14 b	3.3 b	1.2 b	8.9 b	0.16 b	3.6 b
LSD (main M effect)	0.15	1.1	0.01	0.6	0.19	1.0	0.01	0.5
Nitrogen levels (N)								
0 kg N ha^{-1}	0.5 a	3.6 a	0.14 a	1.3 a	0.6 a	3.7 a	0.17 a	1.4 a
60 kg N ha^{-1}	1.0 b	7.9 b	0.13 ab	3.5 b	1.2 b	8.5 b	0.14 b	3.7 b
120 kg N ha^{-1}	1.2 c	9.3 c	0.12 b	4.1 c	1.4 b	10.3 c	0.13 b	4.3 c
LSD (main N effect)	0.11	0.80	0.01	0.4	0.18	1.04	0.01	0.6

Numbers followed by different letters in a column within a set are significantly different at $p \leq 0.05$ by the least significant difference test.ns: not significant.

3.4 Grain yield of rice

The grain yield of rice significantly varied with year of experiment, site location, rice straw mulch and nitrogen levels (Table 1). Average grain yields of rice were lower in 2014 than in 2015 and at the upper site (Site 1) than at the lower site (Site 2).

There was a significant rice straw mulch effect on rice grain yield (Table 1). Average over the two growing seasons, grain yields of rice were significantly higher in rice straw mulch treatments compared with non-mulch treatments by 22 and 40% at Site 1 and Site 2, respectively.

Rice grain yields significantly increased with increase in nitrogen levels (Table 1). Increases in yield were 1.9 Mg ha^{-1} and 2.5 Mg ha^{-1} at Site 1 and Site 2, respectively, when 60 kg N ha^{-1} and when no nitrogen was applied. Increase in nitrogen level from 60 kg N ha^{-1} to 120 kg N ha^{-1} enhanced rice grain yield by 1.0 Mg ha^{-1} and 0.3 Mg ha^{-1} at Site 1 and Site 2, respectively.

There was a significant interaction effect of rice straw mulch and nitrogen fertilization on grain yield of rice (Table 2). At both sites and for the two tillage systems, grain yields of rice were higher under rice straw mulch and nitrogen fertilization compared with the yields under rice straw mulch alone or nitrogen fertilization alone (Fig. 4).

Table 2: p-value from the analysis of variance for root biomass (RB), shoot biomass (SB), root to shoot ratio (RS) and grain yield (Yield) of rice during the growing seasons (July-November) of 2014 and 2015 under different treatments (tillage systems, rice straw mulch and nitrogen levels) evaluated at two experimental sites

Treatment	2014				2015			
	RB Mg ha^{-1}	SB Mg ha^{-1}	RS Mg Mg^{-1}	Yield Mg ha^{-1}	RB Mg ha^{-1}	SB Mg ha^{-1}	RS Mg Mg^{-1}	Yield Mg ha^{-1}
Site (S)	0.03	0.04	0.39	0.04	0.01	0.02	0.19	0.02
Tillage (T)	0.99	0.69	0.90	0.79	0.67	0.33	0.98	0.44
Rice straw (M)	0.002	0.03	0.03	0.02	0.01	0.04	0.009	<0.001
Nitrogen (N)	<0.001	<0.001	0.04	<0.001	<0.001	<0.001	<0.001	<0.001
S x T	0.17	0.35	0.10	0.05	0.07	0.23	0.12	0.10
S x M	0.52	0.84	0.19	0.28	0.36	0.80	0.08	0.49
T x M	0.31	0.63	0.40	0.73	0.20	0.51	0.55	0.86
S x N	0.61	0.29	0.05	0.21	0.43	0.40	0.26	0.52
T x N	0.29	0.67	0.04	0.51	0.15	0.78	0.13	0.61
M x N	0.02	0.03	0.77	0.004	0.01	0.02	0.71	0.03
S x T x N	0.69	0.78	0.59	0.35	0.77	0.52	0.56	0.54
T x M x N	0.45	0.74	0.63	0.94	0.63	0.95	0.70	0.88
S x M x N	0.86	0.84	0.96	0.34	0.56	0.69	0.74	0.71
S x T x M x N	0.97	0.30	0.30	0.09	0.64	0.08	0.15	0.56

3.5 Agronomic efficiency of nitrogen

The agronomic efficiency of nitrogen (AEN) varied from 16 to 66 kg kg^{-1} and from 15 to 62 kg kg^{-1} in 2014 and 2015, respectively. The combination of rice straw mulch and nitrogen fertilizer at 60 kg N ha^{-1} achieved significantly higher agronomic efficiency of nitrogen at the two sites (Fig. 5). The increase in nitrogen level from 60 kg N ha^{-1} to 120 kg N ha^{-1} resulted in the decrease in AEN during the two growing seasons. Results showed that combination of rice straw mulch and 60 kg N ha^{-1} can give rice yield equivalent to that of no straw and 120 kg N ha^{-1} across tillage systems.

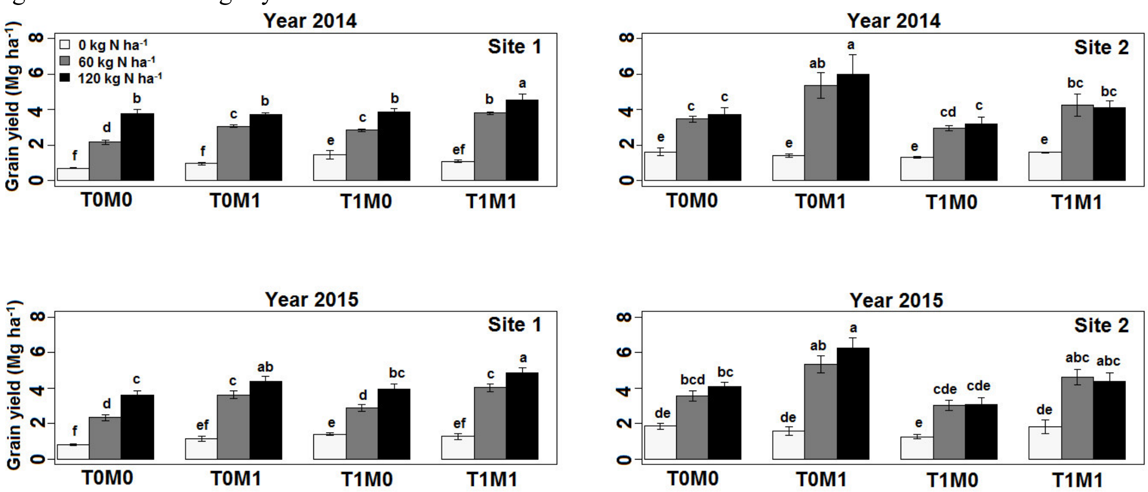

Fig. 4: Tillage and rice straw management effects on grain yield of rice at different nitrogen fertilization levels at the experimental sites 1 and 2 for the growing seasons of 2014 and 2015; T_0M_0: no-tillage, no straw mulch, T_0M_1: no-tillage, straw mulch, T_1M_0: manual tillage, no straw mulch, T_1M_1: manual tillage, straw mulch. Means with the same lower-case letter across treatments within each figure are not significantly different at p ≤ 0.05 by the LSD test. The error bars represent the standard error.

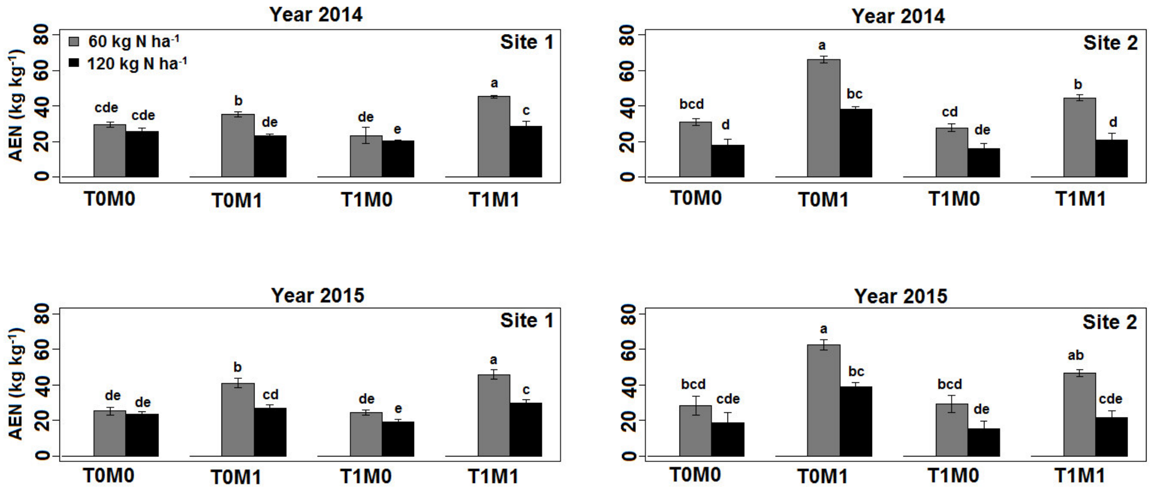

Fig. 5: Agronomic efficiency of nitrogen (AEN) under different tillage systems and rice straw management at the experimental sites 1 and 2 for the growing seasons of 2014 and 2015; T_0M_0: no-tillage, no straw mulch, T_0M_1: no-tillage, straw mulch, T_1M_0: manual tillage, no straw mulch, T_1M_1: manual tillage, straw mulch. Means with the same lower-case letter across treatments within each figure are not significantly different at $p \leq 0.05$ by the LSD test. The error bars represent the standard error.

4. Discussion

Averaged over growing seasons, tillage systems, rice straw management and nitrogen levels, mean rice yields were 2.76 Mg ha^{-1} and 3.32 Mg ha^{-1} at the upper site and at the lower site, respectively. Mean rice yields observed in this study were within the range (1.56 - 3.40 Mg ha^{-1}) of mean upland rice cultivars yields in West Africa (Saito and Futakuchi et al., 2008). Differences in grain yields across years and sites can be explained by rainfall data and soil properties. Average grain yields were lower in 2014 than in 2015 possibly due to the lower cumulative rainfall recorded during the growing season of 2014 (647 mm) compared with that of 2015 (829 mm). The content of soil organic carbon was higher at the lower site (Site 2) than at the upper site (Site 1). Soil organic carbon content was positively correlated to clay content in the soils of the experimental sites. The higher rice yield obtained at the lower site may be associated with higher soil organic carbon and clay contents. Variations in NERICA upland rice yields in northern Benin have been found to depend on pedoclimatic conditions mainly rainfall, soil organic carbon and clay contents (Worou, 2012).

At high nitrogen fertilizer level (120 kg N ha^{-1}), average grain yields of rice were 4.1 Mg ha^{-1} at the upper site (Site 1) and 4.3 Mg ha^{-1} at the lower site (Site 2). Average grain yields of rice under high nitrogen fertilizer level found in this study were within the range (4.0-5.6 Mg ha^{-1}) of maximum grain yield of upland rice obtained with good agricultural practices in experimental fields (Dingkuhn et al., 1998; Ekeleme et al., 2009; Kamara et al., 2010; Saito et al., 2006). At zero-nitrogen fertilizer level, average grain yields of rice were low at the upper site (1.1 Mg ha^{-1}) and at the lower site (1.5 Mg ha^{-1}) and were within the range (0.8-1.6 Mg ha^{-1}) of upland rice yields with zero or low amount of nitrogen fertilizer application (Saito et al., 2013). The large increases in rice yield following nitrogen application provide good evidence of the major role of this mineral nutrient in upland rice production in northern Benin. Similarly to our results, Oikey et al. (2008) reported 1.96 Mg ha^{-1} and 2.67 Mg ha^{-1} higher rice yield with 60 kg N ha^{-1} and 120 kg N ha^{-1}, respectively compared with the yields of zero-nitrogen fertilizer treatments in a Typic Haplustult in Nigeria.

The pattern of increase in grain yield caused by nitrogen fertilizer application and straw mulch points to the interactive mechanisms responsible for the crop responses to both factors on upland soils in northern Benin. Averaged over the two growing seasons, application of 3 Mg ha^{-1} of rice straw mulch increased soil moisture by 0.012 m^3 m^{-3} and reduced soil temperature by 2.4 °C (Fig. 2 and Fig.3). This might have alleviated the soil physical resistance to root development and increased root biomass (Table 1) and the response of rice plants to nitrogen fertilizer application as evidenced by higher agronomic use efficiency of nitrogen found under rice straw mulch and nitrogen fertilization (Fig. 5). Higher soil moisture and lower soil temperature are desirable soil conditions for upland rice production in the Savannah agro-ecological zone in West Africa where air temperatures are constantly high and water scarcity is a major constraint for crop production (Ereinstein et al. 2002). Similarly to our results, Totin et al. (2013) reported higher soil moisture content under rice straw mulch than non-mulch in upland rice fields in Benin. The differences in topsoil temperatures due to rice straw mulch found in our study are similar to those reported from Sahelian soils by Buerkert et al. (2000) with 2 Mg ha^{-1} of millet straw and from Sub-humid soils of western Nigeria by De Vleeschauwer et al. (1980) with 4 to 6 Mg ha^{-1} of rice straw. Furthermore, our results on the combined effects of rice straw much and nitrogen fertilizer application agree with the findings of Rahman et al. (2005) who described higher soil moisture, root biomass, grain yield and nitrogen use efficiency under rice straw mulch compared with bare soil in two consecutive years in an alluvial soil in Bangladesh.

Nitrogen application at 60 kg N ha^{-1} combined with rice straw mulch achieved higher agronomic nitrogen use efficiency than 120 kg N ha^{-1} combined with rice straw mulch. This may be due to higher loss of nitrogen through nitrification and/or denitrification. Increases in N fertilization in most cases result in greater loss of N through N_2O emissions and nitrate leaching (Pelster et al., 2011). Thus, nitrogen application at 60 kg N ha^{-1} combined with rice straw mulch under no-tillage increased soil water availability and the response of rice plants to nitrogen fertilization in northern Benin.

5. Conclusion

Continuous rice cultivation under manual tillage and removal / burning of crop residues is detrimental to the soil and also negative for the crop yield. Adoption of appropriate tillage methods, crop residue application and proper fertilization are beneficial for the soil and the crop yield. These practices are also beneficial for resource-poor farmers by reducing the amount of inorganic fertilizer per unit of harvested product. The findings from our study indicate that no-tillage combined with rice straw mulch and nitrogen fertilization increased soil moisture and decreased soil temperature. Application of rice straw mulch at 3 Mg ha^{-1} and nitrogen fertilizer at 60 kg N ha^{-1} significantly increased the response of rice plants to nitrogen fertilization for the two tillage systems. No-tillage combined with rice straw mulch and 60 kg N ha^{-1} could be used by smallholder farmers to improve rice yield in upland rice fields in northern Benin. Long term studies could be helpful with confirming the effects of these management practices on soil properties and rice yields.

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