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Combined effects of *Stylosanthes guianensis* fallow and tillage management on upland rice yield, weeds and soils in southern Benin

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ABSTRACT

Intensifying upland rice cultivation has resulted in increased weed pressure and declining soil fertility and rice yield in West Africa. Integrated crop management technologies are needed for enhancing rice productivity. A field experiment was conducted from 2006 to 2008 in a Typic Haplustult soil in southern Benin to identify the optimal seeding date of stylo relay-cropped into upland rice, and to evaluate the effects of fallow treatment and tillage management on rice yield, weed biomass and soil properties. *Stylosanthes guianensis* (stylo), a legume species, was used as a short-term fallow crop. Rice was grown once each year and stylo was seeded during the wet season and grown until the next rice-growing season. The effects of fallow treatment and tillage management (no-tillage vs. manual-tillage) on weed biomass during the rice-growing season were evaluated in 2007 and 2008, whereas the effects on rice yield were examined in 2007 alone. Results indicated that stylo can be established as a relay crop with upland rice about 10 days after rice seeding. Stylo fallow reduced weed biomass by 71% and 95% and increased total biomass (weed + stylo + litter) by 594% and 107% at the end of the dry seasons in 2007 and 2008, respectively. No-tillage without stylo fallow increased weed biomass by 62–202% over manual-tillage during the rice-growing seasons, whereas stylo fallow reduced weed biomass by 45–83% and 11–36%, respectively, under no-tillage and manual-tillage management. There were no significant effects of fallow treatment and tillage management on soil organic C, total N, inorganic N and extractable P. Rice yields following stylo fallow were 0.7 Mg ha^{-1} higher than after the natural fallow. Manual-tillage increased rice yield by 0.6 Mg ha^{-1} over no-tillage. Manual-tillage combined with stylo fallow can be recommended to smallholder farmers for improving upland rice productivity.

1. Introduction

In West Africa, the rainfed upland rice ecosystem accounts for about 40% of the total rice area (Balasubramanian et al., 2007). Rice is typically grown under slash-and-burn systems and farmers have relied on extended fallows to restore soil fertility and to reduce problems from insects and weeds, as is typical of slash-and-burn systems elsewhere (e.g., Becker and Johnson, 1999; Roder, 2001). However, rapid population growth and increased demand for land have led to shortened fallow periods, which in turn have resulted in increased weed pressure, and declining soil nutrient availability and rice yield (Becker and Johnson, 1999, 2001). Under these conditions, rice yields are seldom above 2 Mg ha^{-1} in most smallholder farmers' fields. Yield gap analysis shows that weeds and soil nitrogen (N) availability are the major constraints to rice productivity in this region (Becker and Johnson, 2001). It is clear that long-term rice yield cannot be sustained using the current management practices. Therefore, integrated crop management technologies are necessary for sustainable upland rice production.

One of the options is to use improved fallow systems comprising fodder legumes, which can increase fodder availability, suppress weeds, enhance nutrient cycling especially N, and provide cheap nutrient inputs to upland fields (Hauser et al., 2006). *Stylosanthes guianensis* (stylo) is one of the most promising forage legume species for soil fertility improvement and weed suppression in the savanna agroecosystem of West Africa (de Leeuw et al., 1994; Becker and Johnson, 1998; Oikeh et al., 1998; Muhr et al., 1999a, 1999b, 2002; Tarawali et al., 1999). Previous study indicates that N accumulation of stylo ranges from 40 kg ha^{-1} to 200 kg ha^{-1} during the dry season (about eight and half months) and the percentage of N derived from the atmosphere ranges from 63% to 79% in West Africa (Becker and Johnson, 1998). Furthermore, stylo is adapted to low soil fertility and especially tolerant to low soil phosphorus (P) availability (Muhr et al., 1999b). Previous reports from Asia indicate that stylo can be established without competition effect on the accompanying upland

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rice growth (Shelton and Humphreys, 1972; Roder and Maniphone, 1995; Saito et al., 2006). However, relay cropping using stylo is not common among upland rice farmers and information on the optimal seeding time for stylo in West Africa has been limited (Akanvou et al., 2002). To our knowledge, Akanvou et al. (2002) reported only that *Stylosanthes hamata* Taub. can be introduced as early as 3–4 weeks after rice seeding.

Stylo fallow can increase rice yield compared to a natural fallow (Becker and Johnson, 1998; Saito et al., 2006), and it can reduce weed biomass as shown in northern Laos (Roder et al., 1998; Saito et al., 2006). In contrast, weed biomass following stylo fallow did not differ from that following natural fallow in three out of four sites in Côte d'Ivoire (Becker and Johnson, 1998). The reasons for such contrasting results are not clear; but they might be due to differences in agroecosystems, weed species and land preparation practices such as tillage management.

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 the savanna zones where tillage has been the common practice for crop production. Tsuji et al. (2000) reported that rice yield is higher in no-tillage management than that in conventional tillage management in two out of three years in Japan. However, there is limited information regarding the effect of no-tillage management on upland rice productivity in West Africa. The results from several studies in this region were reported in a book published in 1986 (Gupta and O'Toole, 1986), and these showed that there is no significant difference in rice yield between no-tillage and tillage management practices. Further research is needed to examine the effects of no-tillage management on upland rice yield and on weed infestation.

The objectives of this study, therefore, were (1) to identify the optimal seeding date for stylo that is relay-cropped into upland rice, so that rice yield is not reduced, yet stylo establishment is adequate for high biomass accumulation during the fallow period, and (2) to evaluate the effects of stylo as a dry-season fallow crop between rice crops, tillage management, and their interaction on upland rice yield, weeds, and soil properties in the savanna of West Africa. Our specific hypotheses tested in this study are that (1) stylo can be established as a relay crop with upland rice about 10 days after rice seeding, and (2) integrated crop management technologies (fallow treatment + tillage management + rice cultivar) can contribute to increased rice yield, reduced weed pressure and improved soil properties.

Table 1
Rainfall (mm) expressed as monthly and annual values at the Africa Rice Center (AfricaRice) experimental farm in Cotonou, Benin.

	2006	2007	2008	Long term (1987–2008)
January	5	0	2	13
February	8	17	2	26
March	54	57	72	60
April	107	112	99	135
May	220	120	217	183
June	255	521	434	260
July	95	176	247	116
August	8	88	12	61
September	147	111	153	131
October	135	97	243	140
November	26	21	50	35
December	0	73	33	18
Total	1060	1395	1563	1173

2. Materials and methods

An upland rice experiment was conducted in two fields at the experimental farm of the Africa Rice Center (AfricaRice) in southern Benin (2°19′E, 6°25′N, 15 m asl.). The center is located in the coastal savanna zone, and the soil is classified as Typic Haplustult, according to the US Soil Taxonomy. The two fields were within 15 m of each other in a gently-sloping area with relative difference in elevation between the two fields of about 0.6 m. Field 1 was located at the upper part, and Field 2 was at the lower part of the toposequence. These fields were located in the relatively lower area of the farm. When it rains heavily, runoff water flows into the bottom of this study area. The topsoil (0–15 cm) showed sand and clay contents of 80% and 13%, respectively, in Field 1 and 64% and 21% in Field 2 (hydrometer method; Bouyoucos, 1951). In both fields, upland rice was grown during the previous 2005 wet season.

Weather data were collected during this study period from 2006 to 2008 (Table 1). The experiment was conducted under rainfed conditions, except for supplemental irrigation during the two weeks after seeding in 2007 and 2008 to ensure uniform establishment of rice plants. The average annual rainfall was around 1200 mm, and about 82% of the rain fell during the two wet seasons (April–July and September–October). Total rainfall during the rice-growing season (April–August) was lowest in 2006 (Table 1), especially in June and July. Rainfall in May 2007 was lower than in the other two years, but very high in June 2007 and 2008 compared with the long-term mean values (Table 1).

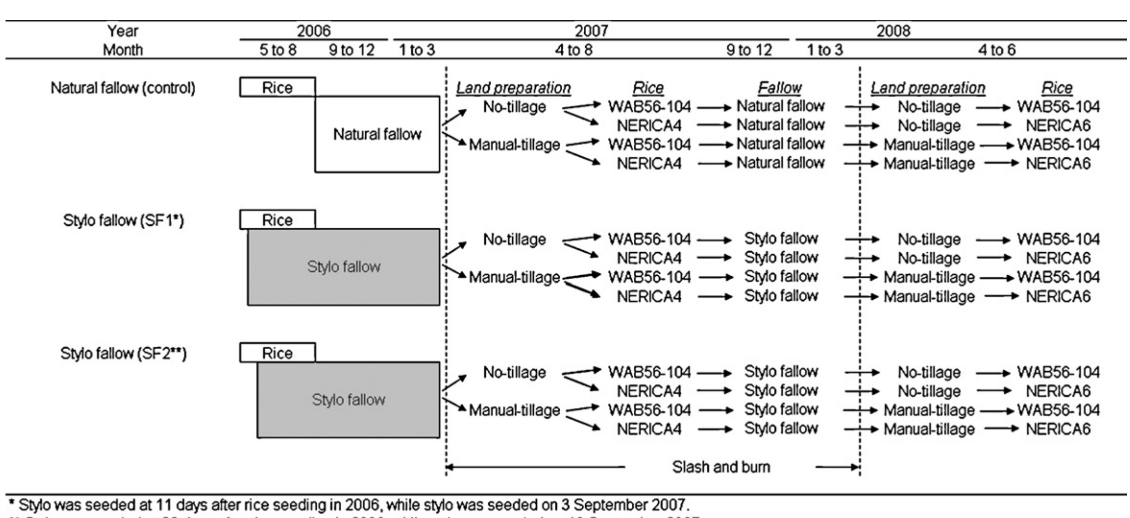

Fig. 1. Experiment cropping calendars.

Land preparation (tillage) at both fields in 2006 was done manually using hand hoes, as commonly practiced in this study area. An improved, early-maturing rice cultivar, WAB56-104 (*Oryza sativa* L.) was monocultured [control; natural fallow after rice cropping (NF)] or relay-cropped with stylo [ILRI 164 (CIAT 184 cv. Pucallpa)] in 2006 (Fig. 1). Stylo was seeded on two different dates following rice seeding: at 11 days (SF1) and 21 days (SF2) in 2006 (where SF denotes stylo fallow).

The experiment was a randomized complete block design with three replications in each field. Individual plot size was 3 m × 6 m. Rice was seeded on 11 May 2006 by placing about four rice seeds into dibbled holes about 2 cm deep (spaced at 0.25 m × 0.25 m). After emergence, plants were thinned to two plants per hill. Basal fertilizer of 15–15–15 (N–P_2O_5–K_2O) was applied at a rate of 200 kg ha^{-1}, with a further 18 kg N ha^{-1} of urea fertilizer applied at 30 days after rice seeding. On both application dates, fertilizer was applied by broadcasting on the surface without incorporating into the soil. Stylo seeds were dipped into water of approximately 80 °C for 10 min prior to seeding to break seed dormancy. Stylo was seeded at the rate of 10 kg ha^{-1} in rows between the rice rows at 0.75 m intervals and with 0.125 m separation from the rice hills. Weeds were controlled manually as necessary. Rice was harvested on 7–22 August from an area of 13.75 m^2 for yield determination (reported at 14% moisture basis).

From August 2006 to March 2007, the fallow vegetation including stylo, remained on the field until the subsequent rice cropping (Fig. 1). At slashing time in March 2007, weed and stylo biomass were determined from the whole plot, and litter biomass was measured from an area of 3 m^2. All fallow vegetation was slashed and burnt. After that, each plot for fallow treatment was split into two sub-plots, each sized at 3 m × 3 m, to study tillage management [no-tillage (NT) and manual-tillage (MT)]. In the MT, tillage was done manually once by using hoes to open up the soil to a depth of about 15 cm. Each sub-plot was further split into two sub-sub-plots of size 1.5 m × 3 m each to serve as cultivar treatment. The two rice cultivars used in 2007 were WAB56-104 and the New Rice for Africa (NERICA) cultivar, NERICA4 (WAB450-IBP-91-HB; *O. sativa* × *O. glaberrima* interspecific progeny) (Jones et al., 1997). The rice was dibble-seeded on 26 April using the same method as in the previous year. No fertilizer was applied. Weed biomass was measured at the time of weeding on 9 and 29 May, and on 2 July by randomly throwing a 1 m^2 frame into any two spots within the evaluation area of 2.5 m^2. Rice was harvested for yield determination on 7–9 August from an area of 2.5 m^2.

Stylo was seeded on 3 and 18 September 2007 using the same method as in the previous year (after rice harvest) for SF1 and SF2, respectively (Fig. 1). The seeding was delayed to evaluate the subsequent effect of stylo fallow on rice growth and weed biomass and to avoid any potential negative effect of seeding stylo on the accompanying upland rice growth and weed biomass. Weeding was done once in these fallow treatments. From September 2007 to March 2008, fallow vegetation including stylo remained on the field until the subsequent rice cropping. At slashing time in March 2008, weed and stylo biomass were determined from the whole sub-plot area, and litter biomass was measured from an area of 2 m^2. All fallow vegetation was slashed and burnt.

The experimental design for 2008 followed the same pattern as in the previous year, except that NERICA4 was replaced with NERICA6 (WAB450-IBP-160-HB; *O. sativa* × *O. glaberrima* interspecific progeny) (Fig. 1). The rice was dibble-seeded on 25 April using the same method as in the previous year. Weed biomass was measured at the time of weeding on 6 and 21 May following the same method as used in the previous year. However, the rice plants failed completely because of unexpected flooding due to heavy rainfall in mid-June (about 200 mm within three days), and the experiment was discontinued.

Soil samples (0–15 cm), consisting of six cores each of 32 mm diameter per sub-plot (tillage management), were collected at rice seeding in 2008, air-dried and sieved for soil analysis following the analytical procedures of the International Institute of Tropical Agriculture (1982). The content of soil organic carbon (C) was determined by chromic acid digestion and total N by Kjeldahl digestion. Samples were extracted with 1:2 (w/w) soil:1N KCl solution and analyzed for nitrate and ammonium using a Technicon Auto-Analyzer II. Inorganic N content was a summation of NH_4–N and NO_3–N concentration. Extractable P content was determined using the Bray-1 (0.25 M HCl + 0.03 NH_4F) method.

The data collected were analyzed using combined analysis of variance (ANOVA) in the General Linear Model procedure of SAS (SAS Institute, 2003) to determine (1) the effects of field location, fallow treatment and their interactions on rice yield in 2006, and stylo, weed and litter biomass at slashing time in 2007; (2) the effects of field location, fallow treatment, tillage management and their interactions on stylo, weed and litter biomass at slashing time in 2008, and soil properties collected in 2008; and (3) the effects of field location, fallow treatment, tillage management, cultivar treatment and their interactions on weed biomass during the rice-growing season in 2007 and 2008, and rice yield in 2007.

The analysis of data for (2) was done as a split-plot design across two fields with fallow treatment in the main plot and tillage management in the sub-plot. The analysis of data for (3) was done as a split–split plot design across two fields with fallow treatment in the main plot, tillage management in the sub-plot and rice cultivar treatment in the sub–sub plot. We considered the effects of field, fallow treatment, tillage management and cultivar treatment as fixed, while replication was considered as a random effect. Mean comparisons were made using the LSD ($p < 0.05$). Data on parameters such as rice yield and weed biomass averaged across two fields were presented, unless there were large interaction effects with field.

Relationships between fallow biomass including stylo and weed biomass at slashing time, and rice yield or weed biomass during rice-growing seasons in this study were compared with those from previous studies in West Africa (Becker and Johnson, 1998) and northern Laos (Saito et al., 2006). In this comparison, litter biomass was not included in the fallow biomass, in line with these previous studies (Becker and Johnson, 1998; Saito et al., 2006).

3. Results

3.1. *Effect of field location on rice yield, and stylo and weed biomass*

Mean rice yield in the lower field (Field 2) was 0.8 and 1.9 Mg ha^{-1} higher than in the upper field (Field 1) in 2006 and 2007, respectively (Tables 2 and 3). Although fertilizer was applied in 2006 only, rice yield averaged across the two fields was lower in 2006 than in 2007 (1.0 Mg ha^{-1} vs. 2.2 Mg ha^{-1}). This was possibly due to water stress in 2006 (Table 1). Rainfall was lower in June and July 2006 than in the same period in 2007. This period corresponded to the rice reproductive growth stage. Rice plants are known to be more sensitive at this stage than at other growth stages. Rice yield was not positively related to rainfall in May, which corresponded to the early vegetative growth stage.

Weed biomass during the rice-growing season was 64% and 50% smaller in Field 1 than in Field 2 in 2007 and 2008, respectively (Table 3). Weed pressure varied between the 2007 and 2008 rice-growing seasons. Weed biomass averaged over all treatments at the first two weeding regimes in the two fields was 0.6 and 0.2 Mg ha^{-1} in 2007 and 2008, respectively (Table 3). Major weed species observed on 20 May 2008 were *Celosia trigyna*, *Mollugo nudicaulis*, *Cyperus rotundus*, *Oldenlandia corymbosa* and *Digitaria*

Table 2
Effect of seeding date of stylo relay-cropped with rice yield (Mg ha^{-1}) in 2006 and fallow biomass (stylo, weed and litter; Mg ha^{-1}) at slashing time in 2007.

Treatment	Rice yield in 2006	At slashing time in 2007			
		Stylo biomass	Weed biomass	Litter biomass	Total fallow biomass***
Field					
Field 1	0.6	7.4	0.2	5.1	12.7
Field 2	1.4	6.9	0.4	5.5	12.9
LSD (0.05, main field effect)	0.62	ns	0.177	ns	ns
Fallow treatment					
Natural fallow (NF)	1.0	0.0	0.5	2.0	2.6
Stylo fallow (SF1*)	0.9	12.0	0.1	7.0	19.1
Stylo fallow (SF2**)	1.1	9.5	0.2	6.9	16.6
LSD (0.05, main fallow treatment effect)	ns	1.91	0.23	1.01	1.82

Source of variation	Degree of freedom	Probability level of F				
ANOVA summary						
Field (S)	1	0.03	0.46	0.04	0.06	0.77
Fallow treatment (F)	2	0.81	<0.01	<0.01	<0.01	<0.01
S × F	2	0.91	0.82	0.20	0.03	0.07

* Stylo was seeded at 11 days after rice seeding in 2006, while stylo was seeded on 3 September 2007 (after rice harvest).
** Stylo was seeded at 22 days after rice seeding in 2006, while stylo was seeded on 18 September 2007 (after rice harvest).
*** Total fallow biomass = stylo + weed + litter biomass.

horizontalis in Field 1, while *Oldenlandia corymbosa*, *Celosia trigyna*, *Mollugo nudicaulis*, *Eleusine indica*, and *Eragrostis tenella* were observed in Field 2. At the end of the dry season in 2007 and 2008, stylo biomass and total fallow biomass (stylo + weeds + litter biomass) did not differ significantly between the two fields (Tables 2 and 4).

3.2. Effect of fallow treatment on rice yield, and stylo and weed biomass

Stylo seeded at 11 (SF1) or 21 (SF2) days after rice seeding in 2006 did not reduce rice yield relative to NF (Table 2). Following a dry-season fallow, total fallow biomass at slashing time in 2007 was highest in SF1 and lowest in NF (Table 2). A similar trend was observed for the total fallow biomass at slashing time in 2008 (Table 4). The 2008 total fallow biomass in SF1 and SF2 was 46% lower than that in 2007. This could be due to the fact that stylo was seeded after rice harvest in 2007, whereas it was seeded during the early rice-growing season in 2006. Mean weed biomass over the two fields was 71% and 95% lower in SF1 and SF2 than in NF at slashing time in 2007 and 2008, respectively (Tables 2 and 4).

Table 3
Rice yield (Mg ha^{-1}) in 2007 and weed biomass (Mg ha^{-1}) during the rice-growing season in 2007 and 2008.

Treatment	Rice yield in 2007	Weed biomass	
		2007	2008
Field			
Field 1	1.2	0.3	0.13
Field 2	3.1	0.9	0.26
LSD (0.05, main field effect)	1.30	ns	ns
Fallow treatment			
Natural fallow (NF)	1.7	1.0	0.26
Stylo fallow (SF1)	2.4	0.3	0.14
Stylo fallow (SF2)	2.4	0.5	0.17
LSD (0.05, main fallow treatment effect)	ns	ns	0.097
Tillage			
No-tillage (NT)	1.8	0.7	0.23
Manual-tillage (MT)	2.5	0.5	0.15
LSD (0.05, main tillage management effect)	0.36	ns	0.059
Cultivar			
WAB56-104	2.1	0.6	0.19
NERICA*	2.2	0.5	0.19

Source of variation	Degree of freedom	Probability level of F		
ANOVA summary				
Field (S)	1	0.02	0.09	0.07
Fallow treatment (F)	2	0.09	0.16	0.04
S × F	2	0.63	0.47	0.90
Tillage management (T)	1	<0.01	0.24	0.02
S × T	1	0.45	0.58	0.38
F × T	2	0.97	0.02	0.42
S × F × T	2	0.42	0.14	0.55
Cultivar (C)	1	0.64	0.14	0.73
S × C	1	0.73	0.94	0.33
F × C	2	0.41	0.33	0.92
T × C	1	0.02	0.57	0.67
S × F × C	2	0.33	0.47	0.24
F × T × C	2	0.16	0.50	0.87
S × T × C	1	0.01	0.81	0.29
S × F × T × C	2	0.51	0.39	0.11

* NERICA4 was used in 2007, while NERICA6 was used in 2008.

Table 4
Fallow biomass (stylo, weed, and litter; Mg ha^{-1}) at slashing time in 2008.

	Stylo biomass	Weed biomass	Litter biomass	Total fallow biomass
Field				
Field 1	3.8	0.7	3.1	7.7
Field 2	4.0	1.4	2.8	8.2
Fallow treatment				
Natural fallow (NF)	0.0	2.8	1.8	4.6
Stylo fallow (SF1)	7.0	0.1	3.6	10.7
Stylo fallow (SF2)	4.7	0.2	3.6	8.5
LSD (0.05, main fallow treatment effect)	1.36	1.36	0.80	2.20
Tillage management				
No-tillage (NT)	4.1	1.0	3.1	8.2
Manual-tillage (MT)	3.7	1.1	2.9	7.7

Source of variation	Degree of freedom	Probability level of F			
ANOVA summary					
Field (S)	1	0.52	0.25	0.12	0.43
Fallow treatment (F)	2	<0.01	<0.01	<0.01	<0.01
S × F	2	0.83	0.28	0.09	0.20
Tillage management (T)	1	0.34	0.56	0.36	0.23
S × T	1	0.51	0.86	0.39	0.80
F × T	2	0.75	0.66	0.34	0.12
S × F × T	2	0.09	0.88	0.97	0.04

Table 5
Rice yield (Mg ha^{-1}) of two cultivars averaged over three fallow treatments.

Treatment	No-tillage (NT)	Manual-tillage (MT)
Field 1		
WAB56-104	0.9	1.4
NERICA4	1.0	1.5
LSD (0.05)	ns	ns
Field 2		
WAB56-104	2.5	3.7
NERICA4	2.9	3.3
LSD (0.05)	ns	0.37

The main effect of fallow treatment was not significant at $p = 0.05$ for weed biomass during the rice-growing season in 2007 (Table 3). Weed biomass was significantly lower in SF1 than in NF during the 2008 rice-growing season. When SF1 and SF2 were compared with NF, weed biomass in SF1 and SF2 was 65% and 41% significantly lower than NF in 2007 and 2008 rice-growing seasons, respectively.

There was no significant effect of fallow treatment on rice yield in 2007 (Table 3). The failure to detect an effect (as well as on weed biomass during the 2007 rice-growing season) was partly due to the experiment being designed primarily to evaluate the effects of tillage management and fallow treatment × tillage management interaction rather than the main effect of fallow treatment. But, the positive effect of stylo fallow on rice yield was apparently large. Rice yields were increased by up to 0.7 Mg ha^{-1} more in SF1 and SF2 than in NF.

3.3. Effects of tillage on rice yield and stylo and weed biomass

Effect of tillage management on weed biomass and the total fallow biomass at slashing time were examined in 2008 only (Table 4). There was no significant effect of tillage management on either parameter. During the rice-growing season in 2008, weed biomass was lower in manual-tillage (MT) than in non-tillage (NT), whereas the difference was not significant in 2007 ($p = 0.24$). There was a significant fallow treatment × tillage management interaction effect on weed biomass during the 2007 rice-growing season (Table 3). Weed biomass was significantly lower in SF1 and SF2 than NF under NT (0.3 Mg ha^{-1} vs. 1.6 Mg ha^{-1}), but not for MT. Similarly, the difference in weed biomass between SF1 and SF2, and NF in 2008 tended to be larger in NT than in MT (0.15 Mg ha^{-1} vs. 0.07 Mg ha^{-1}).

Rice yield was 0.6 Mg ha^{-1} higher in MT than in NT in 2007 (Table 3). The effect of fallow treatment × tillage management interaction on rice yield was not significant.

3.4. Cultivar performance and cultivar× tillage management interaction on rice yield and weed biomass

There was no significant main effect of rice cultivar on rice yield and weed biomass during the 2007 rice-growing season (Table 3). There were significant effects of tillage management × cultivar and field × tillage management × cultivar interactions on rice yield. Rice yields did not differ significantly ($p > 0.05$) between the two cultivars in both tillage managements in Field 1 and in NT in Field 2 (Table 5). In contrast, WAB56-104 produced 0.4 Mg ha^{-1} higher yield than NERICA4 in MT in Field 2.

3.5. Effects of field location, fallow treatment and tillage management on soil properties

The contents of soil organic C, total N, and inorganic N were significantly ($p < 0.05$) higher in the lower field (Field 2) than in the upper field (Field 1), whereas extractable P did not differ significantly between the two fields (Table 6). Soil organic C, total N, and inorganic N contents in Field 2 were positively related to clay and silt contents in the soils. The higher rice yields obtained in Field 2 may be associated with higher organic C, total N and inorganic N contents. The fallow treatment had no significant effects on soil properties. There were no significant effects of tillage management and fallow treatment × tillage management interaction on the soil properties evaluated in this study.

4. Discussion

This study confirmed previous studies in Laos which indicated that stylo could be established as a relay crop with upland rice to replace the natural fallow vegetation (Shelton and Humphreys, 1972; Saito et al., 2006). In relay cropping with upland rice to suppress weed growth during the subsequent dry season and obtain higher biomass accumulation until the end of the dry

Table 6
Soil properties at rice seeding in 2008.

		Soil organic C (g kg^{-1})	Total N (g kg^{-1})	Inorganic N (g kg^{-1})	Extractable P (mg kg^{-1})
Field					
Field 1		6.6	0.47	23	23
Field 2		11.4	0.92	235	26
LSD (0.05, main field effect)		2.45	0.302	103.8	ns
Fallow treatment					
Natural fallow (NF)		8.8	0.65	120	23
Stylo fallow (SF1)		9.1	0.74	153	26
Stylo fallow (SF2)		9.1	0.70	114	24
Tillage management					
No-tillage (NT)		9.0	0.69	123	24
Manual-tillage (MT)		9.0	0.69	135	24
Source of variation	**Degree of freedom**	**Probability level of F**			
ANOVA summary					
Field (S)	1	0.01	0.01	0.00	0.26
Fallow treatment (F)	2	0.95	0.86	0.70	0.33
S × F	2	0.99	0.93	0.72	0.18
Tillage management (T)	1	0.82	0.99	0.63	0.96
S × T	1	0.33	0.77	0.63	0.27
F × T	2	0.59	0.69	0.89	0.41
S × F × T	2	0.35	0.36	0.96	0.72

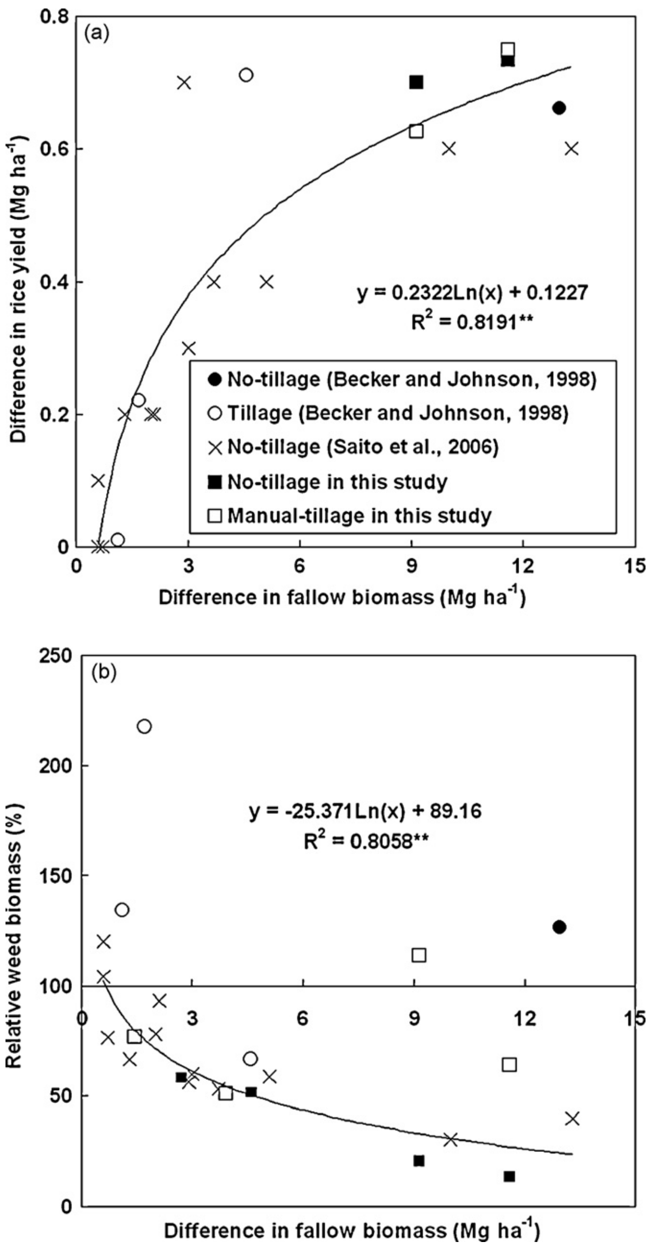

Fig. 2. Relationships between difference in fallow biomass at slashing time (stylo fallow–natural fallow) and (a) difference in rice yield (stylo fallow–natural fallow) and (b) relative weed biomass (stylo fallow/natural fallow × 100) during the rice-growing season. All the data were combined for the regression curve in (a), whereas the data from the result in no-tillage management were combined for the regression curve in (b), except for one experiment from Becker and Johnson (1998). ** indicates significance at 0.01 probability level.

season, our results showed that stylo should be established about 10 days after rice seeding. Delayed stylo seeding resulted in reduced biomass accumulation during the dry season in our study, similar to previously reported studies outside West Africa (Shelton and Humphreys, 1972; Saito et al., 2006).

Rice yields in SF1 and SF2 were up to 0.7 Mg ha^{-1} higher than in NF in agreement with previous studies (Becker and Johnson, 1998; Saito et al., 2006). The relationship between the difference in fallow biomass at slashing time (SF–NF) and the difference in rice yield (SF–NF) from our results and those of Becker and Johnson (1998) and Saito et al. (2006) is shown in Fig. 2. The significant and positive relationship between the difference in fallow biomass and the difference in rice yield indicated that rice yield increase was attributable to the increase in the fallow biomass due to stylo introduction regardless of the different tillage management practices (r = 0.91; $p < 0.01$). Thus, rice yield increase is consistent with increased inputs from the fallow biomass due to stylo introduction. This is consistent with the studies of Akanvou et al. (2000) and Saito et al. (2008).

Our result showing no significant difference in soil properties at rice seeding among fallow treatments is in contrast with the earlier studies of Saito et al. (2006, 2008), who reported that soil N availability was related to the fallow biomass in northern Laos. The reason for this could be due to different sampling depths, 0–5 cm used in their study compared to 0–15 cm used in this study. The deeper soil sampling depth used in this study might have diluted the samples and increased error variability. The effect of burning on soil properties is generally larger in the surface soil than in the sub-surface soil layer (e.g., Kyuma and Pairintra, 1983). Akanvou et al. (2000) indicate that fallow treatments do not affect organic C, total N and extractable P in savanna soils at a depth of 0–20 cm. Therefore, the surface soil (≤5 cm) might be more strongly affected by the fallow treatments. The lack of effect from tillage management on soil properties in this study suggests that it will take more than the single rice-growing season used in the present study to observe any significant impact of tillage management on soil properties.

Our result on the effect of tillage management on rice yield is in contrast with the previous studies that reported no influence of tillage on rice yield in West Africa (Gupta and O'Toole, 1986) and in Japan (Tsuji et al., 2000). But the result was in line with the studies on upland rice in Southeast Asia that showed that tillage management can improve rice yield (Gupta and O'Toole, 1986; Van Keer, 2003; Saito et al., 2009).

The unexpected finding of significant tillage management × cultivar interaction effect on rice yield indicated that the rice cultivars differed in their adaptation to tillage management practices. Joshi et al. (2007) reported that genotypic variation in adaptation to tillage management practices exists in wheat. However, our result was obtained in only one of two fields in one year. Further research is, therefore, needed to validate our finding.

In NT, weed biomass in the upland rice crop was significantly higher in NF than SF in this study. Fig. 2, shows a significant and negative correlation between difference in fallow biomass at slashing time (SF–NF) and difference in relative weed biomass (SF/NF × 100) in the upland rice crop under no-tillage management (r = 0.90; $p < 0.01$), except for one point (outlier) from the Becker and Johnson (1998) study. These suggest that stylo introduction can reduce weed biomass, especially in no-tillage management, due to its effect on biomass accumulation. This result is consistent with previous reports (Roder et al., 1998; Saito et al., 2006). It may have been caused by a 'cool' burn due to the small amounts of biomass accumulated during the short dry-season fallow in NF that failed to destroy weed seeds, or due to a reduced weed seed bank in SF. The dominant weed species was *Chromolaena odorata* in Saito et al. (2006) and in one experiment from Becker and Johnson (1998). But no detailed measurements of weed growth characteristics were conducted in the Becker and Johnson study (1998), and the variability in weed growth and species composition might have contributed to the observed outlier. In MT, the effect of stylo fallow on weed biomass was smaller than in NT in both years. The relative weed biomass in Fig. 2 was not related to the difference in the fallow biomass in tillage management. Becker and Johnson (1998) reported that stylo fallow does not consistently reduce weed biomass during the rice-growing season in fields that were tilled during land preparation. They indicated that weed biomass was weakly but positively related to inputs from higher nutrient accumulation by the fallow vegetation, suggesting that the weeds responded to the improved soil fertility. This was not, however, the case in this study. In plots where stylo was not introduced in our study, no-tillage increased weed biomass by 62–202% over manual-tillage during the rice-growing seasons. Similar results were previously reported (Gupta and O'Toole, 1986; Van Keer, 2003; Saito et al., 2009).

Rice yield responded to stylo fallow at the rate of 70 kg grain/kg stylo seeds in this study (the yield increase was 0.7 Mg ha^{-1} and the seeding rate for stylo was 10 kg ha^{-1}). Estimate of stylo seeds/rice price ratio in Benin is about 7.5 (US$ 3/kg for stylo seeds and US$ 0.4/kg for unhusked rice). Thus, introducing stylo fallow appears profitable. However, this analysis did not take account of increased labor inputs due to stylo introduction, such as seeding stylo and land preparation of stylo fallow for the subsequent rice cropping, as well as benefits of stylo fallow such as reduced weed infestation and increased fodder availability. Further research is therefore needed to quantify the profitability of a stylo fallow system and to examine whether the system is acceptable to smallholder farmers.

5. Conclusions

This study addresses the research hypotheses that (1) stylo can be established as a relay crop with upland rice; and (2) integrated crop management technologies can contribute to increased rice yield, reduced weed pressure, and improved soil properties. Our results indicate that stylo can be established about 10 days after rice seeding. Replacing the natural fallow vegetation with stylo appeared to increase rice yield both under no-tillage and manual-tillage management, whereas the effect of stylo fallow on weed biomass during the rice-growing season was higher with no-tillage management than with manual-tillage management. Rice yield was higher in manual-tillage management than no-tillage management, irrespective of different fallow treatments. The yield increases in both tillage management treatments and the reduced weed biomass in no-tillage management were correlated with biomass accumulation during the fallow period. There were no significant effects of fallow treatment and tillage management on soil organic C, total N, inorganic N and extractable P. Combining manual-tillage management with stylo fallow appears to be an effective strategy for improving upland rice productivity, and should therefore be included as components of integrated crop management technologies in the savannas of West Africa.

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