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Soil tillage practices and crops rotations effects on yields and chemical properties of a lixisol in Burkina Faso

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ABSTRACT

Objective: To improve soil chemical properties and crops productivity, this study was conducted from 2008 to 2015, on lixisoil in a research station, using reduced soil tillage and leguminous plant cover.

Methodology and Results: Three soil tillage practices in main plot (T1 = no tillage with direct sowing, T2 = minimum tillage by soil scarifying with IR12 tool and T3 = conventional tillage with animals drawn plough) were compared and combined to four crops rotation systems, in a split-plot experimental design. Soil chemical characteristics and crops yields were evaluated. The results showed that tillage practices did not influence significantly the soil chemical properties, but soil organic matter contents, nitrogen, phosphorus and potassium were lower in conventional tillage plots (T3) compared to minimum tillage (T2) and no tillage (direct sowing). Rotations did not significantly influence nitrogen and soil organic matter contents, even the leguminous mucuna insertion in the rotation during three years. After 8 years, crops rotations improved significantly cotton (*Gossypium hirsutum* L.) and maize (*Zea mays* L.) yields. The yield increases were respectively +7, +23 and +43%, with one, two and three years of mucuna insertion into rotations. No tillage (direct sowing) and minimum tillage (scarifying with IR12) were as efficacy as conventional tillage on Mucuna and maize yields whereas cotton yield, with minimum tillage (T2) was significantly higher than no tillage (T1).

Conclusion and application of results: The study showed that conventional tillage with mouldboard plough, appear to be the soil tillage practice, which led to soil properties degradation. Crops rotations with the use of leguminous mucuna allowed reducing soil N contents decreases. No tillage (direct sowing) and minimum tillage (scarifying with IR12) showed same efficacy with conventional tillage on cotton, maize and mucuna yields, which were improved after mucuna insertion into crops rotations. Therefore, tillage suppression or its reduction combined to one year leguminous cover plant insertion in rotation (mucuna-cotton-maize) could be used for crops diversification and sustainable productivity in cotton and cereals based production systems.

Keywords: Tillage practices, crops rotations, plant cover, soil fertility, yields, Burkina Faso.

RESUME

Effets des techniques de travail du sol et des rotations sur les rendements des cultures et les propriétés chimiques d'un sol ferrugineux tropical au Burkina Faso

Objectif: L'étude vise à évaluer les effets de la réduction du travail du sol et de l'introduction d'une légumineuse en plante de couverture dans les rotations sur les propriétés chimiques du sol et la productivité des cultures.
Méthodologie et résultats: Le dispositif expérimental est un split-plot comportant trois modes de travail du sol en traitement principal (T1: zéro labour, T2: scarifiage à la dent IR12 en traction bovine et T3: labour à la charrue en traction bovine) combinés à quatre rotations à base de coton (*Gossypium hirsutum* L.), de maïs (*Zea mays* L.) et du *mucuna,* utilisé comme plante de couverture. Les caractéristiques chimiques du sol et les rendements des cultures ont été évalués. Les résultats montrent que les teneurs en matière organique, en azote, en phosphore et en potassium du sol, statistiquement homogènes, ont baissé avec le labour (T3) par rapport au scarifiage à la dent IR 12 (T2) et au zéro labour (T1). L'introduction d'une légumineuse dans les rotations n'a pas influencé les teneurs en azote et en matière organique du sol, mais elle a, par contre, significativement augmenté les rendements du cotonnier et entrainé, sur le maïs, des suppléments de production respectifs de +7, +23 et +43%, avec une, deux et trois années de *mucuna* dans les rotations.
Conclusion et application des résultats: L'étude a permis de montrer que le labour est le mode de préparation du sol le plus défavorable pour les caractéristiques chimiques du sol, peu influencées par les rotations des cultures, qui réduisent la baisse des teneurs en N avec l'utilisation de la légumineuse mucuna. Le zéro labour (semis direct) et le scarifiage à la dent IR12 se sont révélés aussi efficaces que le labour sur les rendements des cultures, eux même, améliorés par l'introduction du mucuna dans les rotations. De ce fait, une suppression du labour ou sa réduction, combinée à une année d'insertion de la légumineuse mucuna, en plante de couverture, dans la rotation (mucuna-coton-maïs), pourrait être envisagée pour le maintien des propriétés du sol et une amélioration durable des rendements dans les systèmes de production à base de coton et de céréales.

Mots clés: travail du sol, rotations culturales, plante de couverture, fertilité du sol, rendements, Burkina Faso.

INTRODUCTION

Soil fertility degradation is considered to be_one of the major limiting factors of agricultural productivity in Sub-Saharan African countries (Bationo *et al.*, 2012; Busari *et al.*, 2015). Among the reasons of this progressive land degradation, cultivation systems, soil tillage practices, are particularly often cited by various studies (Ouattara *et al.*, 2006; Maia *et al.*, 2010; Schneider *et al.*, 2010). In Burkina Faso, crop production systems and soil fertility management are particularly based on the use of mineral fertilizers associated to soil tillage; mainly ploughing at the beginning of the rainy season (Ouédraogo *et al.*, 2014; Traoré, 2016). However, cotton (*Gossypium hirsutum* L.) is grows on soils which generally have a low fertility level, fragile and sensitive to erosion (Zougmoré *et al.*, 2006; Sawadogo *et al.*, 2008; Barro *et al.*, 2009). These soils are generally subjected to the runoff and erosion phenomena, depending on excessive tillage, involving a loss of soil nutrients and organic matter (Pallo *et al.*, 2009; Barro *et al.*, 2009; Pouya *et al.*, 2013). Thus, mechanized tillage using tractor and animal traction, increases soil physical and chemical degradation than manual cultivation and fallow, leading to soil acidification (Koulibaly *et al.*, 2014). Conventional farming practices are no longer sustainable as far as soil fertility is concerned. Moreover, strong anthropic pressure on soil leads to a drastic decrease of crops yields (Yaméogo *et al.*, 2013; Traoré, 2016). In addition, for a few decades throughout the world, ploughing has been decreasing at the profit of various tillage practices, ranging from reduced tillage without reversal, to direct seeding (Reddy *et al.*, 2003, Veiga *et al.*, 2008; Lefèvre, 2013). In Burkina Faso cotton farming areas, various studies recommended a reduction of ploughing frequency for better preservation of soil properties (every two years) and a minimum tillage, in crop production (Ouattara *et al.*, 2006). Rainfall irregularity involves unfavourable conditions with ploughing, which lead to sowing delays, and therefore reduce cotton yields (Traoré, 2016). In Burkina Faso, as for the majority of West African countries, several fertility management practices including using of organic matter, mineral fertilizers or introduction of leguminous plants into rotations were adopted for their efficacy (Bado, 2002; Mando *et al*., 2005; Bationo *et al*., 2012; Karuma *et al*., 2014). It is therefore necessary, for a sustainable soil fertility management, to analyze tillage practices effects and to determine the impact of crops rotations including leguminous plant as cover crop. The objective of this study is to determine the tillage practices effects associated to crops rotations integrating a plant cover, on soil chemical properties and crops yields. Research hypothesis is that soil properties and crops yields can be improve by soil tillage reduction and by introduction of a leguminous plant as cover crop in rotations.

MATERIALS AND METHODS

Experimental site and material description: This study was conducted in 2008 on the research station of Farako-bâ (4^0 20 W Longitude, 11^0 06 N Latitude, 405 m). Climate is south-Sudanese type, with a rainy season ranging between May and October, and a dry season, from November to April. During 2008 to 2015, the annual rainfall was between 831 and 1289 mm, received during 62 to 79 days. Plants cropped were cotton and maize (*Zea mays* L.) completed with a cover plant. Cotton variety FK 37, with 150 days cycle and 3.5 t ha-1 of seed cotton as potential yield was used. Maize variety FBC 6, with 110 days cycle length, and 3.5 t ha-1 as potential yield, was also cultivated. *Mucuna cochinchinensis* variety, which cycle is from 130 to 150 days (Figure 1), was integrated as cover crop in cotton and maize rotations. Soil tillage practices consisted to use the plough for conventional tillage and "IR12 tool" for a minimum tillage by scarifying soil with animal traction.

A) Soil recovered by Mucuna **B) Flowering of Mucuna** **C) Fruiting of Mucuna**

Figure 1: Pictures of leguminous plant cover *Mucuna cochinchinensis.*

Mineral fertilizers: Mineral fertilization of cotton and maize was ensured by NPKSB (14-18-18-6S-1B) and urea [CO $(NH_2)_2$] with 46% nitrogen content.

Experimental design: The study was conducted on a lixisol, in a split-plot experimental design with three tillage practices combined to four crops rotations with four replications. Main treatments consist of three tillage practices: T1= no-till (direct sowing), T2 = scarifying by IR12 tool and T3 = conventional tillage with animals drawn plough. Secondary treatments were four crop rotations (Table 1):

R1 = Cotton-maize (control without cover plant) - (c-m),

R2 = Mucuna-cotton-maize (one year of Mucuna in three years rotation) - (1*muc*-c-m),

R3 = Mucuna-mucuna-cotton-maize (two years of Mucuna in four years rotation) - (2*muc*-c-m),

R4 = Mucuna-mucuna-mucuna-cotton (three years of Mucuna in four years rotation) - (3*muc*-c).

Experimental unit (60 m ²) was a plot consisted of five 15 m length rows, spaced 0.80 m apart. A surface of 240 m² was assigned to each main plot and 2280 m² for the experiment. In the first year of study (2008), soil was ploughed by a tractor at an average depth of 25 cm, and then harrowed. From the second year (2009), according to above mentioned main treatments, conventional tillage was carried out by animal traction (15 cm of depth), and minimum tillage by IR12 tool scarifying, from 7 to 10 cm depth, depending on soil moisture status. Cotton, maize and *mucuna* were sown in seed holes, drawn aside by

0.40 m, then thinned out 15 days after emergence, with two plants per seed hole, to obtain a theoretical density of 62 500 plants per hectare. Crop sowings were carried out between June 27 and July 24, depending on years (Table 1).

Table 1. Crops rotations, sowing dates and rainfall from 2008 to 2015

Rotations	Years							
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
R1. c-m	Cotton	Maize	Cotton	Maize	Cotton	Maize	Cotton	Maize
R2. 1 *muc*-c-m	Mucuna	Cotton	Maize	Mucuna	Cotton	Maize	Mucuna	Cotton
R3. 2 *muc*-c-m	Mucuna	Mucuna	Cotton	Maize	Mucuna	Mucuna	Cotton	Maize
R4.3 *muc*-c	Mucuna	Mucuna	Mucuna	Cotton	Mucuna	Mucuna	Mucuna	Cotton
Soil tillage dates	17/06	10/07	30/06	10/07	6/07	18/07	25/06	6/07
Sowing dates	27/06	24/07	7/07	16/07	10/07	23/07	2/07	9/07
Rainfall (mm)	1139,6	908,0	1289,5	831,0	1089,0	1126,0	1142,9	1050,9

Cotton and maize mineral fertilization was carried by 150 kg ha^{-1} of cotton fertilizer (14-18-18-6S-1B). It was applied 15 days after the emergence, and by 50 kg ha^{-1} of urea, at 40 days. *Mucuna cochinchinensis* plant, used as cover crop was not fertilized. Weeds control on these two crops, was carried out by herbicides applications (800 g ha^{-1} of diuron for cotton and 1250 g ha^{-1} of pendimethalin for maize) supplemented by mechanical weeding. Cotton protection was ensured by usual insecticides applying indoxacarb (150 g ha^{-1}), at 30 and 44 days after emergence, "zeta-cypermethrin (12 g ha^{-1}) - profenofos (200 g ha^{-1})" association at 58 th and 72 th days, and "cypermethrin (36 g ha^{-1}) - acetamiprid (8 g ha^{-1})" association with the 86 th and 100 th days. After harvests, the stems of cotton and maize were exported out of field while the *mucuna* biomass was preserved on the soil.

Measurements: Soil was sampled in sub plots to determine the evolution of it chemicals characteristics. Thus, 96 soil samples were taken on 0-10 and 10-20 cm layers depth in 2011 and 2015. All the soil samples were crushed and filtered at 2 mm, for analyzes at the laboratory of the Bureau National des sols of Burkina Faso. The crop yields were evaluated by the harvest of three central lines of each sub plot.

Data analysis: Collected data were subjected to an analysis of variance (ANOVA), by GENSTAT 9.2. Student-Newman-Keuls test was used for means comparison when the analysis of variance reveals significant differences between treatments at 5% probability level.

RESULTS

Tillage practices and rotations effects on soil organic matter and nitrogen content: Tillage practices and crops rotations did not have significant effects on soil organic matter and nitrogen contents, which decreased from 2011 to 2015, as well as on 0-10 cm surface layer than deeper 10-20 cm layer (Table 2). On 0-10 cm layer of soil, from 2011 to 2015, organic matter contents decrease was 20%, in rotations (cotton-maize) R1 and (mucuna-cotton-corn) R2. A moderate decrease of soil organic matter from 4 to 12% was noted in rotations R3 (2 m-c-m) and R4 (3muc-c), where Mucuna was used during two and three years in four years crop rotation. Soil tillage practices did not influence nitrogen contents, which, by 2011 to 2015, decrease was more important in rotations R1 and R2, compared to R4 rotation (Table 2). Introduction of leguminous plant Mucuna in rotations R2 (1muc-c-m), R3 (2 m-c-m) and R4 (3muc-c) during respectively, one, two and three years, did not improve soil nitrogen content, as well as on surface 0-10 cm and 10-20 cm depth layer, compared to control rotation R1 (cotton-corn) without leguminous plant.

Table 2. Soil organic matter and nitrogen contents (layer 0-10 cm and 10-20 cm) according to the tillage practices under crops rotations at 2011 and 2015.

Treatments	Soil organic matter (%)				Nitrogen (%)			
	0-10 cm		10-20 cm		0-10 cm		10-20 cm	
	2011	2015	2011	2015	2011	2015	2011	2015
Soil tillage								
T1. No tillage	1,00	0,87	0,89	0,78	0,049	0,046	0,044	0,041
T2. Scarifying IR 12	1,01	0,83	0,90	0,68	0,048	0,044	0,045	0,036
T3. Conventional tillage	0,99	0,86	0,93	0,75	0,048	0,045	0,044	0,039
Crops rotations								
R1. c-m	1,05 [a]	0,84	0,88	0,70	0,051	0,044	0,043	0,038
R2. 1 *muc*-c-m	1,02	0,82	0,92	0,75	0,049	0,044	0,045	0,039
R3. 2 *muc*-c-m	1,01	0,89	0,93	0,78	0,048	0,046	0,045	0,041
R4.3 *muc*-c	0,91	0,87	0,90	0,72	0,046	0,046	0,046	0,037
Probability (5%)								
Soil Tillage	0,974	0,457	0,843	0,061	0,963	0,379	0,962	0,191
Rotations	0,348	0,248	0,886	0,422	0,357	0,549	0,852	0,491
Soil Tillage x Rotations	0,880	0,022	0,690	0,976	0,921	0,925	0,708	0,046

R1: Cotton-Maize; R2: *Mucuna*-Cotton-Maize; R3: *Mucuna-Mucuna*-Cotton-Maize; R4: *Mucuna-Mucuna-Mucuna*-Cotton.

Tillage practices and rotations effects on soil phosphorus content: According to analysis of variance (Table 3), the effects of soil tillage practices and crops rotations on P total and P available contents were statistically significant, particularly on the surface 0-10 cm depth layer. On this layer, in 2011 and 2015, scarifying with IR12 tool (T2) was statistically equivalent to conventional tillage (T3) and decreased significantly total P content compared to no tillage (T1). However, conventional tillage (T3) induced more important available P declining in 0-10 cm depth layer in 2011. Soil tillage practices, in particular scarifying with IR12 tool, is seem to increase total P and available P content, compared to zero tillage (T1). In rotations R3 and R4 with respectively two and three years of mucuna on four years crops rotation, the total P contents on 0-10 cm decreased significantly compared to those of rotations R1 (cm) and R2 (1m-c-m). Available P contents of R1 rotation (without leguminous plant) were significantly higher than those of rotations R2, R3 and R4, with respectively, one, two and three years of mucuna in four years crops rotations. Results showed that in rotations, total and available P contents decrease with the increase of mucuna cultivation years in rotations. These contents increased by 2011 to 2015, as well on the surface on 0-10 cm as in-depth on 10-20 cm. In 2015, the interaction between soil tillage practices and crops rotations were significant for total P contents whose high values were noted in absence soil tillage, with zero tillage.

Tillage practices and rotations effects on soil potassium: Results in Table 4 shows, in 2011 and 2015; that soil tillage, by scarifying with IR12 tool and conventional tillage, produced a reduction in soil total K and available K contents. In 2015 and on 0-10 cm layer, compared to zero tillage (T1), total K and available K contents significantly decreased with conventional tillage (T3), statistically equivalent to minimum tillage by scarifying with IR12 tool (T2). Soil tillage practices decreased potassium contents, which are accentuated by conventional tillage than scarifying with IR12 tool. Crops rotations did not have significant effects on soil total K and available K contents (Table 4). These contents seem to decrease in rotations R3 and R4 where the lowest potassium contents were noted compared to rotations R1 and R2. Generally, although interactions between soil tillage practices and crops rotations are not significant, from 2011 to 2015, total K decreased whereas an improvement of available K contents was noted on the layer 0-10 cm.

Table 3. Tillage practices effects on contents of total phosphorus and available phosphorus under crops rotations at 2011 and 2015 (0-10 and 10-20 cm)

Treatments	P total (mg kg^{-1})				P ass. (Bray1) (mg kg^{-1})			
	0-10 cm		10-20 cm		0-10 cm		10-20 cm	
	2011	2015	2011	2015	2011	2015	2011	2015
Soil tillage								
T1. No tillage	111 ^{a}	118 ^{a}	110 ^{a}	116 ^{a}	2,09 ^{a}	5,53 ^{a}	1,21 ^{a}	2,67 ^{a}
T2. Scarifying IR 12	103 ^{b}	108 ^{b}	104 ^{a}	114 ^{a}	2,02 ^{a}	4,57 ^{a}	1,32 ^{a}	2,31 ^{a}
T3. Conventional tillage	107 ^{ab}	111 ^{ab}	103 ^{a}	105 ^{a}	1,62 ^{a}	5,58 ^{a}	1,44 ^{a}	2,63 ^{a}
Crops rotations								
R1. c-m	113 ^{a}	112 ^{a}	105 ^{a}	112 ^{a}	2,44 ^{a}	7,89 ^{a}	1,61 ^{a}	2,92 ^{a}
R2. 1 muc-c-m	109 ^{a}	112 ^{a}	108 ^{a}	113 ^{a}	1,82 ^{b}	5,73 ^{b}	1,24 ^{b}	2,62 ^{a}
R3. 2 muc-c-m	107 ^{ab}	115 ^{a}	105 ^{a}	109 ^{a}	1,74 ^{b}	3,66 ^{c}	1,22 ^{b}	2,46 ^{a}
R4.3 muc-c	98 ^{b}	111 ^{a}	105 ^{a}	112 ^{a}	1,64 ^{b}	3,64 ^{c}	1,22 ^{b}	2,14 ^{a}
Probability (5%)								
Soil Tillage	0,017	0,029	0,083	0,334	0,075	0,239	0,075	0,549
Rotations	0,018	0,903	0,811	0,886	0,027	< 0,0001	0,027	0,262
Soil Tillage x Rotations	0,413	0,039	0,388	0,815	0,725	0,816	0,725	0,823

R1: Cotton-Maize; R2: *Mucuna*-Cotton-Maize; R3: *Mucuna*-*Mucuna*-Cotton-Maize; R4: *Mucuna*-*Mucuna*-*Mucuna*-Cotton. Values followed with the same letter in each column did not differ statistically according to Student-Newman-Keuls test at 5% level of probability. s: significant; ns: not significant.

Table 4: Content of K total and K available according to tillage practices under crops rotations at 2011 and 2015 (layer 0-10 and 10-20 cm).

Treatments	K total (mg kg^{-1})				K disponible (mg kg^{-1})			
	0-10 cm		10-20 cm		0-10 cm		10-20 cm	
	2011	2015	2011	2015	2011	2015	2011	2015
Soil tillage								
T1. No tillage	1441 ^{a}	1314 ^{a}	1774 ^{a}	1506 ^{a}	86 ^{a}	96 ^{a}	75 ^{a}	59 ^{a}
T2. Scarifying IR 12	1380 ^{a}	1171 ^{b}	1563 ^{a}	1396 ^{a}	79 ^{a}	86 ^{ab}	69 ^{a}	57 ^{a}
T3. Conventional tillage	1318 ^{a}	1155 ^{b}	1468 ^{a}	1385 ^{a}	71 ^{a}	77 ^{b}	62 ^{a}	51 ^{a}
Crops rotations								
R1. c-m	1338 ^{a}	1265 ^{a}	1575 ^{a}	1464 ^{a}	78 ^{a}	91 ^{a}	64 ^{a}	57 ^{a}
R2. 1 muc-c-m	1494 ^{a}	1217 ^{a}	1622 ^{a}	1431 ^{a}	84 ^{a}	93 ^{a}	68 ^{a}	57 ^{a}
R3. 2 muc-c-m	1377 ^{a}	1190 ^{a}	1595 ^{a}	1421 ^{a}	81 ^{a}	87 ^{a}	70 ^{a}	59 ^{a}
R4.3 muc-c	1311 ^{a}	1180 ^{a}	1616 ^{a}	1400 ^{a}	71 ^{a}	74 ^{a}	72 ^{a}	50 ^{a}
Probability (5%)								
Soil Tillage	0,407	0,017	0,191	0,168	0,467	0,448	0,615	0,568
Rotations	0,071	0,159	0,909	0,803	0,297	0,169	0,728	0,304
Soil Tillage x Rotations	0,300	0,134	0,303	0,605	0,406	0,615	0,487	0,628

R1: Cotton-Maize; R2: *Mucuna*-Cotton-Maize; R3: *Mucuna*-*Mucuna*-Cotton-Maize; R4: *Mucuna*-*Mucuna*-*Mucuna*-Cotton. Values followed with the same letter in each column did not differ statistically according to Student-Newman-Keuls test at 5% level of probability.

Tillage practices and rotations effects on soil pH: pH water values ranging between 4.58 and 5.40, were not statistically influenced by soil tillage practices (Figure 2) and crops rotations (Figure 3). From 2011 to 2015, pH decreased as well on 0-10 cm layer as in-depth 10-20 cm layer. The highest decrease of pH water, which is 7% on 0-10 cm, was observed with the conventional tillage and a decrease of 3 and 4%, respectively, in zero tillage and scarifying with IR12 tool. The reduction in the pH by soil tillage practices is more important in-depth 10-20 cm layer, than on surface (0-10 cm) layer. On this strongly acid soil, from 2011 to 2015, pH decrease into crops rotations, were between 4 to 5% on 0-10cm layer, and 6 to 8%, in-depth 10-20 cm layer. In rotations R3 and R4, respectively, with two and three years of leguminous plant mucuna, pH declining was important as well as in rotations R1 and R2. In general, compared to the conventional tillage and scarifying, pH declining was reduced by zero tillage.

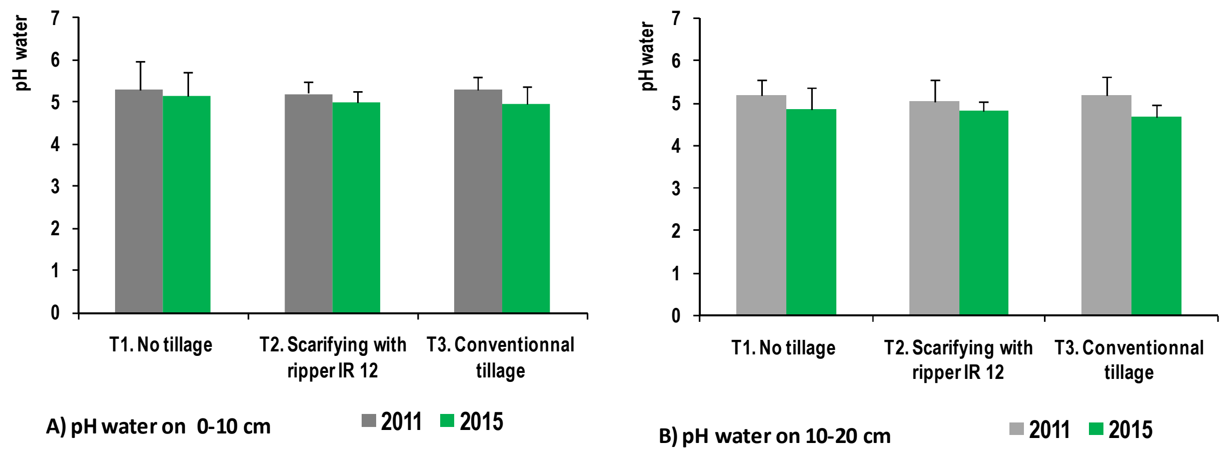

Figure 2: Soil tillage practices effects on pH on 0-10 cm (A) and 10-20 cm (B) (2011 and 2015)

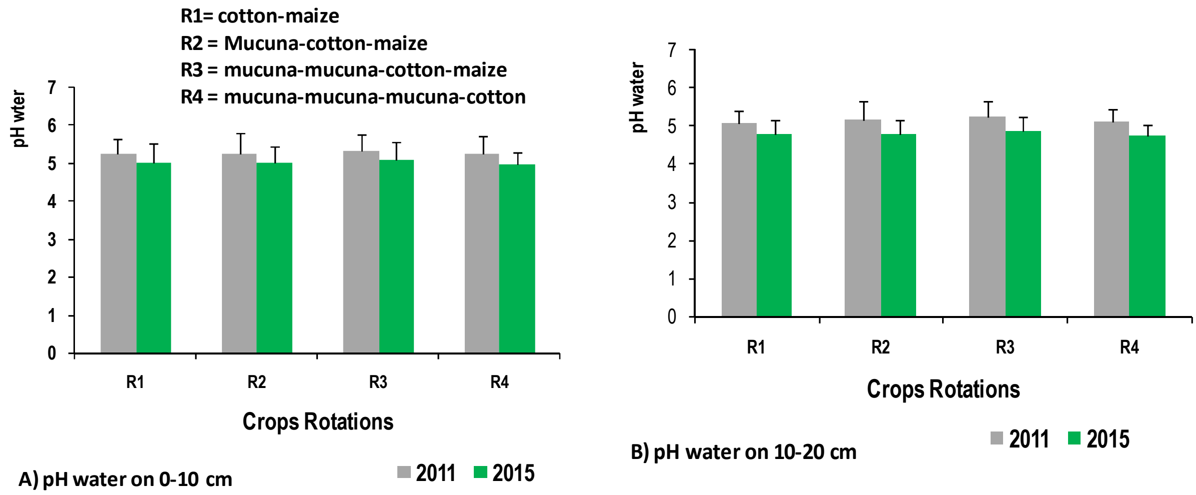

Figure 3: Crops rotations effects on soil pH on 0-10 cm (A) and 10-20 cm (B) (2011 and 2015).

Tillage practices and rotations effects on crops yields: Variations of yields according to soil tillage practices into each crop rotation are presented in table 5. In R1 rotation, conventional tillage had a positive effect on seed cotton yield in 2008 whereas it caused in 2013 on maize, a significant decrease of yield compared to scarifying with IR12 tool. In general, in four crops rotations, the yields were comparable with soil tillage (Table 5). After 8 years experimentation (2008 to 2015), soil tillage practices did not have significant effects on mucuna ($p = 0.167$) and maize ($p = 0.753$) yields (Table 6). Minimum tillage (scarifying with IR12 tool) improved seed cotton yield (+4%) compared to conventional tillage which appeared to be better than no tillage (direct sowing). In opposite, no tillage (direct sowing) and minimum tillage gave better yields of maize which improvements were, respectively + 17 and + 13%, compared to conventional tillage. Crops rotations had significant effects on seed cotton and mucuna yields (Table 6). Compared to cotton-maize rotation (R1), introduction of a leguminous plant into rotations improved seed cotton yields with +7, +23 and +43%, respectively in rotations R3 (2muc-c-m), R2 (1muc-c-m) and R4 (3muc-c).The rotations R2 (1muc-c-m) and R3 (2muc-c-m), with respectively, one and two years of *mucuna* cultivation, improved significantly the mucuna yield compared to rotation R4 (3muc-c). Rotations R4 (3muc-c), R3 (2muc-c-m) and R2 (1muc-c-m) allowed best yields of seed cotton, maize and mucuna, respectively. Compared to cotton-maize rotation without cover plant (R1), generally adopted by farmers, the rotation with one-year mucuna insertion (R2), gave yield surplus of seed cotton (+ 23%) and maize (+4%). Interactions between soil tillage practices and crops rotations were statistically significant on yields of cotton ($p = 0.048$) and maize ($p = 0.003$). The best options for cotton growing are conventional and minimum tillage (scarifying with IR12 which) which could be associate to no tillage (direct sowing) for maize production improvement.

Table 5. Crops yields variations into rotations according to tillage practices

Soil tillage	Crops rotations	2008	2009	2010	2011	2012	2013	2014	2015
		Kg ha^{-1}							
Crops		Cotton	Maize	Cotton	Maize	Cotton	Maize	Cotton	Maize
T1. No tillage	R1 c-m	882 ^{b}	1153 ^{a}	1080 ^{a}	2428 ^{a}	752 ^{a}	2076 ^{ab}	926 ^{a}	2023 ^{a}
T2. Scarifying IR 12		1050 ^{a}	1111 ^{a}	1231 ^{a}	2670 ^{a}	857 ^{a}	2395 ^{a}	965 ^{a}	2325 ^{a}
T3. Conventional tillage		1076 ^{a}	710 ^{a}	1336 ^{a}	1866 ^{a}	817 ^{a}	1527 ^{b}	1293 ^{a}	1578 ^{a}
Probability (5%)		0,035 (s)	0,126 (ns)	0,244 (ns)	0,16 (ns)	0,718 (ns)	0,040 (s)	0,688 (ns)	0,340 (ns)
Crops		Mucuna	Cotton	Maize	*Mucuna*	Cotton	Maize	*Mucuna*	Cotton
T1. No tillage	R2 1muc-c-m	849 ^{a}	767 ^{a}	1372 ^{a}	433 ^{a}	903 ^{a}	2176 ^{a}	1269 ^{a}	597 ^{a}
T2. Scarifying IR 12		852 ^{a}	645 ^{b}	1586 ^{a}	582 ^{a}	1087 ^{a}	2334 ^{a}	1389 ^{a}	1037 ^{a}
T3. Conventional tillage		832 ^{a}	643 ^{b}	1285 ^{a}	369 ^{a}	876 ^{a}	1693 ^{a}	1389 ^{a}	906 ^{a}
Probability (5%)		0,985 (ns)	0,041 (s)	0,863 (ns)	0,373 (ns)	0,696 (ns)	0,147 (ns)	0,919 (ns)	0,129 (ns)
Crops		Mucuna	*Mucuna*	Cotton	Maize	*Mucuna*	*Mucuna*	Cotton	Maize
T1. No tillage	R3 2muc-c	965 ^{a}	776 ^{a}	1251 ^{a}	2527 ^{a}	1092 ^{a}	521 ^{a}	903 a	2386 ^{a}
T2. Scarifying IR 12		813 ^{a}	632 ^{a}	1275 ^{a}	1590 ^{a}	1261 ^{a}	656 ^{a}	1256 a	2002 ^{a}
T3. Conventional tillage		998 ^{a}	641 ^{a}	1191 ^{a}	2308 ^{a}	1377 ^{a}	593 ^{a}	1172 a	2454 ^{a}
Probability (5%)		0,641 (ns)	0,597 (ns)	0,963 (ns)	0,368 (ns)	0,679 (ns)	0,825 (ns)	0,430 (ns)	0,490 (ns)
Crops		*Mucuna*	*Mucuna*	*Mucuna*	Cotton	*Mucuna*	*Mucuna*	*Mucuna*	Cotton
T1. No tillage	R4 3muc-c	755 ^{a}	601 ^{a}	622 ^{a}	692 ^{a}	1364 ^{a}	585 ^{a}	833 ^{a}	944 ^{a}
T2. Scarifying IR 12		790 ^{a}	477 ^{a}	688 ^{a}	771 ^{a}	864 ^{a}	568 ^{a}	694 ^{a}	873 ^{a}
T3. Conventional tillage		949 ^{a}	498 ^{a}	693 ^{a}	1020 ^{a}	1087 ^{a}	634 ^{a}	625 ^{a}	1097 ^{a}
Probability (5%)		0,394 (ns)	0,625 (ns)	0,598 (ns)	0,359 (ns)	0,264 (ns)	0,976 (ns)	0,653 (ns)	0,732 (ns)

R1 : Cotton-Maize ; R2 : *Mucuna*-Cotton-Maize ; R3 : *Mucuna-Mucuna*-Cotton-Maize ; R4 : *Mucuna-Mucuna-Mucuna*-Cotton. Values followed with the same letter in each column did not differ statistically according to Student-Newman-Keuls test at 5% level of probability. s : significant ; ns : not significant.

Table 6. Height years tillage practices and rotations effects on crops yields (2008-2015)

Treatments		Seed cotton	Maize	Mucuna
			Kg ha^{-1}	
Soil Tillage	T1. No tillage	862 ^{b}	1884 ^{a}	823 ^{a}
	T2. Scarifying with ripper IR 12	1003 ^{a}	1817 ^{a}	792 ^{a}
	T3. Conventional tillage	964 ^{ab}	1613 ^{a}	830 ^{a}
Crops rotations	R1. c-m	797 ^{b}	1700 ^{a}	-
	R2. 1 muc-c-m	983 ^{ab}	1769 ^{a}	911 ^{a}
	R3. 2 muc-c-m	849 ^{ab}	1844 ^{a}	824 ^{a}
	R4.3 muc-c	1143 ^{a}	-	710 ^{b}
Probability (5%)	Soil Tillage	0,036	0,167	0,753
	Rotations	0,031	0,663	0,006
	Soil Tillage x Rotations	0,048	0,003	0,438

R1 : Cotton-Maize ; R2 : *Mucuna*-Cotton-Maize ; R3 : *Mucuna-Mucuna*-Cotton-Maize ; R4 : *Mucuna-Mucuna-Mucuna*-Cotton. Values followed with the same letter in each column did not differ statistically according to Student-Newman-Keuls test at 5% level of probability.

DISCUSSION

Tillage practices and rotations effects on soil chemical properties: Height year's experimentation results showed that soil tillage practices did not influence soil organic matter content which decrease from 2011 to 2015. Soil organic matter decline, particularly in cotton-maize and mucuna-cotton-maize rotations, was important with conventional tillage due to high level of mineralization and therefore, soil organic carbon degradation (Razafimbelo, 2005; Cookson *et al.*, 2008; Karuma *et al.*, 2014). Using of mucuna during two or three years in four years rotations (R3 and R4), combined to minimum tillage (IR 12 scarification), can prevent soil organic matter declining, because soil is less disturbed and better preserved (Ouattara *et al.*, 2006; Veiga *et al.*, 2008, Lefèvre *et al.*, 2013). In addition, mucuna insertion into the crops rotations, improve a soil surface organic matter compared to carbon losses (Razafimbelo, 2005; Maia *et al.*, 2010; Busari *et al.*, 2014). During 8 years of experimentation, introduction of Mucuna into rotations did not improve nitrogen content, but it also prevented it decrease in surface as well as in depth layer of soil. Razafimbelo (2005) and Vian *et al.*, (2009), pointed out a limited enrichment of soil by cover crop, which is significant for carbon content only on soil surface (0-5 cm) layer. The low level of total phosphorus and available phosphorus contents confirm the poverty in phosphorus which majorit999y characterizes soils in Burkina Faso (Lompo *et al.*, 2009). Although statistically equivalents and compared to zero tillage, minimum and conventional tillage led to a lower total P content at 0-10 cm layer. This depressive effect of conventional tillage on total P was reduced in rotations with two or three years of leguminous plant mucuna, which protects soil from streaming and various nutrients loss, when used as cover crop (Zougmoré *et al.*, 2006; Haruna et Nkongolo, 2015). Moreover, on this layer, available P seems to be better preserved by zero tillage. Tillage increase phosphorus availability, a factor, which could involve a more important soil declining, compared to no tillage (Veiga *et al.*, 2008; Bationo *et al.*, 2012; Baueur *et al.*, 2012). Compared to minimum tillage and zero tillage, conventional tillage also caused lower total K and available K contents, even in rotations R3 (2muc-c-m) and R4 (3muc-c) with mucuna insertion, during, respectively, two and three years into four years rotation. For each considered crops rotations, tillage suppression or it reduction had positive effects, particularly on 0-10 cm of soil, improving majority of nutrients; and confirms conventional tillage consequences on soil chemical properties (Zougmoré *et al.*, 2006, Busari *et al.*, 2014). The pH water values decreased during 2011 to 2015 in all rotations with soil tillage (conventional and minimum tillage) as well as with no tillage (direct sowing). This soil acidification, which generally results in a loss of complex exchangeable bases (Landon, 1991), accentuated with conventional tillage which caused the most important pH decrease. Differences between pH water values in this soil suggest liming (Fabre and Kockmann, 2002) or local calco-magnesian amendments (Koulibaly *et al.*, 2014), to attenuate acidification.

Tillage practices and rotations effects on crops yields: Variations of crops yields from 2008 to 2015 showed that no tillage gave same efficacy than the minimum and conventional tillage. Compared to no tillage, the conventional tillage efficacy on seed cotton yields could be explained by a better water infiltration and favourable rooting condition of cotton during years when rainfall was affected by drought (Son *et al*., 2004; Heddadj *et al*.; 2005, Vian *et al*., 2009). Cumulated tillage practices effects during 8 years, showed minimum tillage (scarifying with IR12) as the most efficient soil preparation technique on yields of cotton. This last technique, by its efficacy on yields confirms the interest of a minimum tillage evoked by various studies (Son *et al*., 2004; Razafimbelo, 2005; Busari *et al*., 2014) and so, could suitably replace conventional tillage. Higher maize yields obtained with minimum and no tillage shows that the conventional tillage could be saved in maize production. That consolidates the recommendations of Ouattara *et al*., (2006) to reduce ploughing frequency in order to preserve soil fertility in cotton cropping systems. Rotations influenced significantly cotton yields because of crops successions, particularly with the introduction into these rotations of mucuna, a leguminous plant cover, which was also beneficial on maize yields. This result confirms the interest in using this leguminous plant, as cover crop since it protects soils and improves yields as well as soil chemical properties (Bado, 2002; Zougmoré *et al*., 2006). Without two or three years of mucuna insertion into rotation, adopting triennial mucuna-cotton-maize rotation could be recommended for its efficacy on yields.

CONCLUSION

This study showed that tillage practices did not statistically influence the main soil chemical properties, in four crop rotations. Soil organic matter, nitrogen, phosphorus and potassium contents decrease with conventional tillage, whereas the pH slightly increased. With mucuna integration in rotations during two or three years, organic matter and nitrogen were better preserved into the soil. No tillage (direct sowing) and minimum tillage (IR12 scarification) gave the same efficacy than the conventional tillage on crop yields. Thus, the suppression of tillage or its reduction can be considered for the implementation of crops without inducing depressive effect on yields. Furthermore, yields are improved in rotations integrating the leguminous cover (Mucuna) whose effects are positive in soil fertility management and production diversification. A combination of reduced tillage (scarification) with crop rotations integrating Mucuna, could contribute to a sustainable soil fertility management. Crop residues management, analysis of soil physical properties and biological modifications are suggested in future investigations of this study.

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