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Research Paper

Long-Term Effects of Crops Residues Management on the Soil Chemical Properties and Yields in Cotton - Maize - Sorghum Rotation System in Burkina Faso

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Bazoumana Koulibaly[1*], Déhou Dakuo[2], Ouola Traoré[3], Korodjouma Ouattara[4], François Lompo[4]

[1]Institute of Environment and Agricultural Research (INERA), 01 BP 208 Bobo-Dioulasso 01, Burkina Faso.
[2] Burkinabe Society of Textile Fibres (SOFITEX), Direction of cotton production development, BP 147, Bobo-Dioulasso, Burkina Faso.
[3] West African Economic and Monetary Union (UEMOA), Ouagadougou, Burkina Faso.
[4]Institute of Environment and Agricultural Research (INERA), 04 BP. 8645 Ouagadougou 04, Burkina Faso.

*Corresponding author. E-mail: bazoumana@hotmail.com
Phone : (226) 70 23 90 05,
Fax : (226) 20 97 01 59,

ABSTRACT

In cotton and cereals production systems, the most important cause of soil fertility degradation is the inappropriate crop residues management. In a long-term experiment carried out from 1982 to 2012, the effects of crop residues management (CRM) during 30 years on soil chemical properties and crops yields were evaluated in a cotton-cereals rotation. The experimental design was non-randomized blocks having 3 treatments. Extensive CRM with exportation of residues was compared to semi-intensive CRM and intensive CRM and recycling the residues into compost and farmyard manure, respectively. The results showed that continuous cropping of soil during 30 years affects significantly ($p < 0.05$), the main chemical characteristics of soil for comparing crop residues management practices. From 25th to 30th years, the decrease of carbon, Nitrogen and total P contents was very high as well as those of exchangeable bases, particularly, Ca^{2+} and Mg^{2+} contents. The cation exchange capacity (CEC) decrease was 63, 31 and 26%, respectively in extensive, semi-intensive and intensive CRM. Recycling crop residues into compost or farmyard manure does not prevent soil chemical degradation and crops yields decrease but allowed to reduce them significantly. Moreover, integrated management of crop residues, a reduction of soil tillage frequency and preventing soil erosion are suggested for a sustainable maintenance of soil chemical properties.

Key words: Crop residues, soil properties, organic and inorganic fertilizers, yields, crop rotation, Burkina Faso.

INTRODUCTION

Maintaining and improving soil quality is crucial for agricultural productivity and environmental quality sustainability for future generations (Kumar and Goh, 2000; Arrouays et al., 2012; Alam et al., 2014). Most soils in Africa exhibit low nutrient levels with a high propensity towards nutrients losses due to their fragile nature (Omotayo and Chukwuka, 2009).

Problems of degradation of soil health are due to imbalance inorganic fertilizer use, inadequate use or no use of organic manures and crop residues (Bationo et al., 2012; Babu et al., 2014). Determination of appropriate crop residues management practices could give a welcome agricultural technology as it will improve and sustain crops yields (Ogbodo, 2011; Lemtiri et al., 2016). In addition to the main nutrients (N, P and K), crop residues contain also substantial amounts of secondary nutrients and micronutrients, then returning back these residues into the soil may be one of the best alternative practices for improving the physical, chemical and biological properties of the poor soils (Borie et al., 2002; Singh et al., 2005; Hiel et al., 2016). With expanding strategies of direct sowing and conservation agriculture often associated to minimum tillage, the use of cover plants or crops residues as mulch, contributed also to protect and improve soil properties

(Nascente et al., 2015).

In the cotton growing zones of Burkina Faso, as well as many parts in the tropics, crop residues are in general, burned or removed from the fields for various domestic uses (Koulibaly et al., 2010; Ogbodo, 2011; Autfray et al., 2012) while their incorporation increases the soil organic matter content (Samra et al., 2003, Lemtiri et al., 2016). These inappropriate practices in continuous cropping are unfavorable to soil fertility maintenance as they lead to low organic matter content affecting soil fertility and also crop yields (Autfray et al., 2012).

A lot of researches highlighted the interest of recycling crops residues in organic manure or their incorporation into soil (Berger et al., 1987; Singh and Sidhu, 2014; Ouandaogo et al., 2016). Using only inorganic fertilizers can compromise the intensification of cotton and cereals production system without calco-magnesian amendments through the application of rock phosphate or dolomite which improve the status of cropped soils. Long-term experiments were implemented and analyzed in many places in the world, to look for sustainable options of cultivated soils management and improve productivity (Vullioud et al., 2004; Wei et al., 2006).

The objective of this study was to evaluate crops residues management (CRM) and fertilization effects on soil chemical properties and crop yields under cotton-maize-sorghum rotation systems through 30 years experiment. These effects are analyzed for better recommendation of integrated soil fertility maintenance and sustainable crops production systems.

MATERIALS AND METHODS

This study was conducted since 1982 at the experimental and seed production farm of Boni (3° 26 ' W Longitude, 11° 32 ' N Latitude and 302 m above sea level) on a lixisol. Climate is of South-Sudanese type, with a rainy season occurring between May and October and a dry season from November to April. In general, the annual rainfall distribution was very irregular and ranged between 723 and 1353 mm with 40 to 75 rainy days.

Non-randomized blocks with 3 replications was used in this experiment covering 6 ha subdivided in 3 plots of 2 ha, each spaced by 4 m (Figure 1). The experimental unit was 0.5 ha (100 m × 50 m) assigned to each treatment. Every year, each plot of 2 ha containing compared treatments was affected to cotton, maize or sorghum and cropped according to a cotton-maize-sorghum rotation system. The compared treatments were three crops residues management practices combined with rock phosphate (25% $P_2 O_5$ and 35% CaO) application and the use of inorganic fertilizers as defined:

T_1: Extensive management of crop residues**:** The straws of maize and sorghum are removed from the field or grazed, while cotton straws were burned. Every three years on the maize sub-plots and 300 kg ha^{-1} of rock phosphate applied after ploughing and harrowing.

T_2: Semi-intensive management of crop residues (by composting): An average of 4 t ha^{-1} of sorghum straws were composted after 45 days of crushing by 20 cows in a traditional cowshed located near the field. During composting process, 300 kg of rock phosphate were mixed with the sorghum straws. Every three years, the compost obtained by recycling sorghum straws was applied on the maize sub-plots at the rate of 6 t ha$^{-1.}$ The mean composition of the compost produced was: 35.2% of organic matter; 2.2 N to 1.9 P to 1.8 K to 0.3 S to 0.64 Ca to 0.15 Mg.

T_3: Intensive management of crop residues (recycled into farmyard manure): An average of 4 t ha^{-1} of sorghum straws were recycled into farmyard manure in a raining season park under only rains watering after 60 days of crushing by 20 cows (Berger et al., 1987). This farmyard manure composition has the following: 34.6% of organic matter; 2.2 N to 1.1 P to 1.7 K to 0.3 S to 2.14 Ca to 0.19 Mg. Every 3 years, 6 t ha^{-1} of farmyard manure combined with 300 kg ha^{-1} of rock phosphate were applied on maize sub-plots.

For T_2 and T_3 plots, maize straws were incorporated into the soil by ploughing at the end of the rainy season, while cotton straws were burned in the field. The annual fertilization (inorganic fertilizers and rock phosphate) applied per hectare was 46 kg N, 25 P, 48 K, 18 S and 1 kg B on cotton; 74 kg N, 25 P, 60 kg K on maize and 46 N, 25 kg P on sorghum.

Plant materials used in this study were improved varieties of cotton (*Gossypium hirsutum* L.), maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* (L.) Moench) with potentials yields of 3 to 4 t ha^{-1}, 4 to 5 t ha^{-1} and 2 to 3 t ha^{-1}, respectively. Every year, before sowing the crops (between May, 20th and July, 10th), each plot was ploughed using a tractor drawn plough at 20 to 25 cm soil depth and then harrowed by conventional tillage. Cotton was sown in rows spaced by 0.80 m and plant distance was 0.40 m. Fifteen days after emergence, cotton plot was thinned to two plants per hill so as to obtain a theoretical stand of 62 500 plants per hectare.

Maize and sorghum were sown using a tractor and thinned with a replanting for sorghum to perform the plants population. The plots were kept weed free by manual weeding combined to herbicides (999 g ha^{-1} métolachlor + 501 g ha^{-1} terbutryne on cotton, 1250 g ha^{-1} pendimethalin on maize and 750 g ha^{-1} terbutryne + g ha^{-1} terbutylazine on sorghum). Cotton pest control was ensured by usual insecticides applied according to recommended procedure.

A liming of all the plots was carried out in 1989 with the amount of 1 t ha^{-1} using lime containing 53% CaO and 35% MgO. In 1995, a subsoiling at 30 to 35 cm soil depth was carried out using chisel before planting *Andropogon gayanus* grass bands to prevent soil erosion. All the main operations of ploughing and sowing are usually done using an intermediate tractor BOUYER of 28 CV power.

Before crops sowing, three mixed soil samples were randomly collected ineach cotton sub-plots, in May, at 0 to 20 cm depth for chemical analysis. All the soil samples (collected at 0 to 20 cm) for each treatment were air-dried, crushed and sieved on 2 mm mesh for laboratory analyses. Soil organic carbon was measured by the Walkley-Black procedure (Walkley and Black, 1934). Total nitrogen was determined by the Micro-Kjeldahl method (Bremmer, 1965). Available P was determined using Bray I method as explained in Page et al. (1982). Soil pH was determined using glass electrode pH meter in a suspension of soil to water at the ratio of 1:25 (Mclean, 1982). Exchangeable cations were determined according to the procedure described by Landon (1991).

Analysis of variance of soil data collected at 6 years frequency corresponding to two cycles of triennial rotation were done using GENSTAT 9.2 software. The test of Student-Newman-Keuls was used for means comparison when the analysis of variance revealed significant differences between treatments at 5% probability.

RESULTS AND DISCUSSION

Crops residues management effects on soil carbon and nitrogen contents

The cropping duration decreased significantly ($p<0.05$) soil C and N contents in all the three crop residues management (CRM) practices (Table 1). After 30 years of continuous cultivation in extensive CRM (T_1), semi-intensive CRM (T_2) and intensive CRM (T_3) practices. The soil organic carbon decline was 43, 29 and 23%, respectively, for annual decrease of 1.4, 0.9 and 0.8%, respectively.

The decline of carbon might be related to the high mineralization rate of soil organic matter (Pallo et al., 2009; Bationo et al., 2012) accentuated by annual ploughing and water erosion effects (Ouattara et al., 2006, Obalum et al., 2012). The C/N ratio values ranging between 10 and 12 (Table 1) confirms this mineralization of soil organic matter (Malhiet al., 2006) for all the compared CRM practices, thereby leading to a decrease of soil nitrogen contents, which is important with residues exportation (Kumar and Goh, 2000; Wei et al., 2006; Traoré et al., 2007; Chitte et al., 2016). Maize straw incorporation into the soil and the use of organic and inorganic fertilizers in semi-intensive CRM and intensive CRM reduced the degradation of soil fertility, particularly, the decline of C and N as these nutrients are important in farming under the tropics (Amedé, 2003; Koulibaly et al., 2010).

Using inorganic fertilization without any organic restitution depress soil chemical characteristics with the cropping duration indicating the limits of the use of this fertilizers because they lead generally to soil nutrients decline and soil acidification (Cattan et al., 2001; Vanlauwe et al., 2005, Koulibaly et al., 2014; Singh and Sidhu, 2014). The soil production potential is then affected by the reduction of the soil carbon stock (Arrouays et al., 2012; Bationo et al., 2012) while it should be considered as a capital to maintain and improve soil quality for sustainable management of cropping systems (Hiel et al., 2016). Autfray et al. (2012) reported that increasing the biomass to be recycled combined to a better management of livestock and avoiding crop residues burning gave a balance in terms of organic fertilization for the large majority of south-Mali exploitations.

Evolution of soil P contents according to crop residues management

In 30 years of continuous cropping, total P (107 to 340 mg kg^{-1}) and available P (18.5 to 21 mg kg^{-1}) contents decreased significantly ($P < 0.05$) in control plots as well as those with compost and farmyard manure application (Table 2). The P values were then established under the critical level contents reported to be 200 and 30 mg kg^{-1} for total P and available P, respectively (Berger et al., 1987, Lompo et al., 2009). The decline of total P which was 25% in all treatments after 25 years (Koulibaly et al., 2010), reached 47, 40 and 28%, respectively in extensive CRM (T_1), semi-intensive CRM (T2) and intensive CRM (T_3) after 30 years.

Available P contents varied from 21 to 6.75 mg kg^{-1}, corresponding to a loss of 68% in 30 years of extensive CRM (Table 2). The available P and total P contents lower than critical level indicate that these soils presented phosphorus deficiency (Traoré et al., 2007). The rock phosphate application combined to the restitution of crop residues increased the phosphorus solubility and release by micro-organisms (Vanlauwe et al., 2015; Lemtiri et al., 2016). According to Fabre and Kockman (2002), liming activates the biological processes and improves the assimilability of phosphorus. Crop residues contain inorganic and organic P forms, easily available for plants and micro-organisms (Babu et al., 2014). Tillage practices can also influence P release from crop residues (Alam et al., 2014). Vanlauwe et al. (2015) showed that mixing crop residue with soil particles by moldboard ploughing resulted in acceleration of crop residues decomposition and subsequently, increased nutrient release.

Evolution of exchangeable bases and CEC of soil according to CRM practices

The soils used in the study are characterized by low reserves in exchangeable bases which decreased significantly after 30 years of continuous cultivation (Table 3). Decline of Ca^{2+} contents from 2.64 to 1.39 $cmol^{+}$ kg^{-1} and

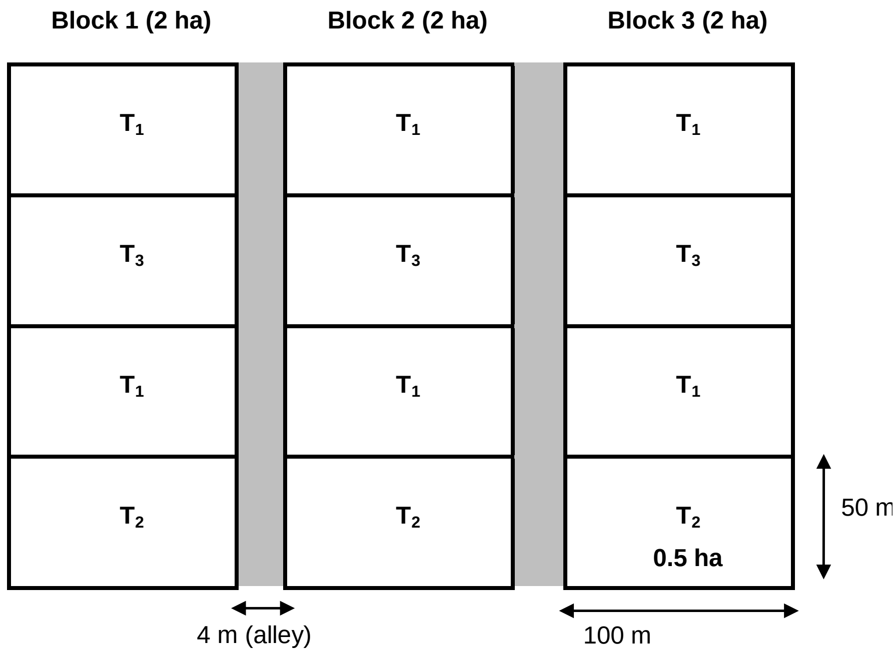

Figure 1: Representation of experiment design at Boni.

Table 1: Variation of soil organic carbon and nitrogen contents on 0 to 20 cm depth at Boni.

Treatments	Cropping duration	C	N	C/N
		g kg-1		
T_1= Extensive CRM*	1 year	9.25 ± 0.02	0.81 ± 0.006	11.50 ± 0.21
	6 years	5.85 ± 0.08	0.55 ± 0.003	10.50 ± 0.78
	12 years	5.55 ± 0.22	0.37 ± 0.003	14.81 ± 2.19
	18 years	5.50 ± 0.04	0.50 ± 0.012	11.21 ± 0.42
	25 years	6.23 ± 0.16	0.49 ± 0.010	12.74 ± 1.58
	30 years	5.25 ± 0.06	0.48 ± 0.006	11.02 ± 0.64
Cumulated decrease over 30 years (%)		43	41	4
T_2 = Semi-intensive CRM	1 year	7.90 ± 0.08	0.74 ± 0.008	10.75 ± 0.85
	6 years	7.25 ± 0.01	0.69 ± 0.001	10.37 ± 0.07
	12 years	7.10 ± 0.07	0.53 ± 0.003	13.45 ± 0.71
	18 years	6.88 ± 0.02	0.63 ± 0.002	11.01 ± 0.16
	25 years	6.56 ± 0.16	0.52 ± 0.010	12.53 ± 1.58
	30 years	5.64 ± 0.08	0.44 ± 0.001	12.76 ± 0.80
Cumulated decrease over 30 years (%)		29	40	-
T_3= Intensive CRM	1 year	7.45 ± 0.11	0.65 ± 0.005	11.52 ± 1.06
	6 years	5.60 ± 0.16	0.53 ± 0.012	10.49 ± 1.56
	12 years	6.30 ± 0.18	0.50 ± 0.002	12.65 ±1.84
	18 years	7.01 ± 0.01	0.56 ± 0.004	12.51 ±0.13
	25 years	7.14 ± 0.01	0.57 ± 0.002	12.46 ± 0.06
	30 years	5.77 ± 0.08	0.55 ± 0.016	10.81 ± 0.76
Cumulated decrease over 30 years (%)		23	16	6
Probability (0.05)	Cropping duration	0.010	0.001	0.045
	Treatments	0.375	0.203	0.946
	Trait × cropping duration	0.002	0.003	0.441

*CRM= Crop residues management. Values after the sign ± represent standard deviation of means.

Table 2: Variation of soil contents of available P and total P according to crops residues management (0 to 20 cm depth) at Boni.

Treatments	Cropping duration	Available P (Bray 1)	Total P
		mg kg-1	
T_1= Extensive CRM*	1 year	21.00 ±1.41	241.50 ± 12.12
	6 years	19.50 ±2.12	279.00 ± 37.98
	12 years	10.07 ± 3.82	232.80 ± 12.45
	18 years	9.00 ±4.26	107.17 ± 20.03
	25 years	7.69 ±2.28	190.97 ± 22.96
	30 years	6.75 ±0.81	127.83 ± 20.55
T_2 = Semi-intensive CRM	1 year	18.50 ± 0.71	279.50 ± 20.51
	6 years	18.00 ± 1.41	296.00 ± 2.83
	12 years	12.63 ± 4.70	330.20 ± 14.42
	18 years	15.28 ± 5.08	221.73 ± 39.21
	25 years	7.87 ± 2.28	199.01 ± 22.96
	30 years	8.16 ± 1.07	167.12 ± 68.77
T_3= Intensive CRM	1 year	19.50 ± 0.71	221.00 ± 5.66
	6 years	18.50 ± 0.71	235.00 ± 14.14
	12 years	16.07 ± 5.71	239.75 ± 15.20
	18 years	10.79 ± 4.44	140.31 ± 66.91
	25 years	6.08 ± 0.11	164.63 ± 12.42
	30 years	7.81 ± 0.91	159.61 ± 46.43
Probability (0.05)	Cropping duration	0.001	<0.0001
	Treatments	0.850	0.001
	Treatment × cropping duration	0.034	< 0.0001

*CRM= Crop residues management. Values after the sign ± represent standard deviation of means.

Table 3: Soils bases reserves and cation exchange capacity according to crops residues management (0 to 20 cm depth) at Boni.

Treatments	Cropping duration	Ca++	Mg++	K+	Na+	SBE	CEC
		Cmol+kg-1					
T1= Extensive CRM*	1 year	2.64	1.05	0.37	0.04	4.10	6.50
	6 years	1.91	0.60	0.15	0.04	2.70	3.32
	12 years	1.95	0.43	0.10	0.05	2.65	4.16
	18 years	1.77	0.36	0.19	0.05	2.36	3.68
	25 years	1.51	0.39	0.12	0.03	2.05	3.22
	30 years	1.39	0.29	0.11	0.05	1.84	3.05
T2 = Semi-intensive CRM	1 year	2.13	0.74	0.35	0.06	3.28	5.42
	6 years	1.95	0.66	0.23	0.05	2.89	3.68
	12 years	2.43	0.62	0.14	0.08	3.37	5.00
	18 years	2.19	0.47	0.19	0.05	2.90	4.46
	25 years	1.50	0.33	0.12	0.03	1.99	3.82
	30 years	1.54	0.45	0.12	0.02	2.12	3.75
T3= Intensive CRM	1 year	2.21	0.86	0.34	0.03	3.43	4.81
	6 years	2.16	0.76	0.21	0.04	3.20	3.70
	12 years	2.71	0.77	0.49	0.05	3.72	6.63

Table 3 Cont:

	18 years	2.16	0.55	0.19	0.03	2.92	3.94
	25 years	2.07	0.54	0.14	0.03	2.77	3.82
	30 years	2.37	0.37	0.13	0.03	2.90	3.56
Probability (0.05)	Cropping duration	0.034	< 0.0001	0.069	0.816	0.001	0.031
	Treatments	0.039	0.008	0.348	0.758	0.016	0.775
	Treatment × cropping duration	0.003	< 0.0001	0.244	0.997	0.002	0.035

*CRM= Crop residues management.

Table 4: Evolution of soils pH depending on cropping durationand CRM (0 to 20 cm depth) at Boni.

Treatments	Cropping duration	pH Water	pH KCl	△pH
T_1 = Extensive CRM*	1 year	6.43 ± 0.11	5.50 ± 0.14	0.92
	6 years	5.95 ± 0.21	4.70 ± 0.28	1.25
	12 years	5.88 ± 0.04	4.93 ± 0.39	0.95
	18 years	5.90 ± 0.42	5.27 ± 0.04	0.63
	25 years	6.33 ± 0.21	5.49 ± 0.01	0.84
	30 years	5.86 ± 0.53	4.69 ± 0.66	1.17
T_2 = Semi-intensive CRM	1 year	6.10 ± 0.00	5.05 ± 0.07	1.05
	6 years	5.93 ± 0.25	5.00 ± 0.14	0.92
	12 years	5.94 ± 0.27	5.34 ± 0.56	0.60
	18 years	5.97 ± 0.48	5.39 ± 0.02	0.58
	25 years	6.27 ±0.21	5.43 ± 0.01	0.84
	30 years	5.56 ± 0.57	4.67 ± 0.93	0.89
T_3= Intensive CRM	1 year	6.35 ± 0.07	5.01 ± 0.21	1.35
	6 years	6.08 ± 0.32	5.38 ± 0.32	0.70
	12 years	6.17 ± 0.30	5.42 ± 0.10	0.74
	18 years	5.99 ± 0.35	5.25 ± 0.35	0.74
	25 years	6.37 ± 0.06	5.62 ± 0.02	0.75
	30 years	5.74 ± 0.09	4.52 ± 0.27	1.22
Probability (0.05)	Cropping duration	0.021	0.009	
	Treatments	0.460	0.781	
	Treat. x Cropping duration	0.309	0.108	

*CRM= Crop residues management. Values after the sign ± represent standard deviation of means.

those of Mg^{2+} from 1.05 to 0.29 cmol+ kg-1 represents cumulated decrease of 47 and 72%, respectively, in extensive CRM plots. This trend is also observed for soil K^+ and Na^+ contents (Table 3), which decline significantly in all the CRM practices and then, confirmed the soil degradation (Landon, 1991; Alam et al., 2014). During 30 years, gradual decline of exchangeable bases resulted primarily from the nutrients uptake by the crops. These negative effects of continuous land cultivation accentuated by crop residues removal without any organic restitution are frequently reported by numerous authors (Wei et al., 2006; Traoré et al., 2007; Singh and Sidhu, 2014). Important decrease of soil Ca^{2+} and Mg^{2+} affect the total exchangeable bases as well as the CEC and damaged adsorbing complex, making it more sensitive to degradation, especially led to soil acidification (Hiel et al., 2016). Cation exchange capacity, while declining from 4.81 to 3.56 cmol+ kg-1 decreased by 26% after 30 years of intensive CRM (T3) versus 31% in semi-intensive CRM (T_2) and 63% in extensive CRM (T_1).

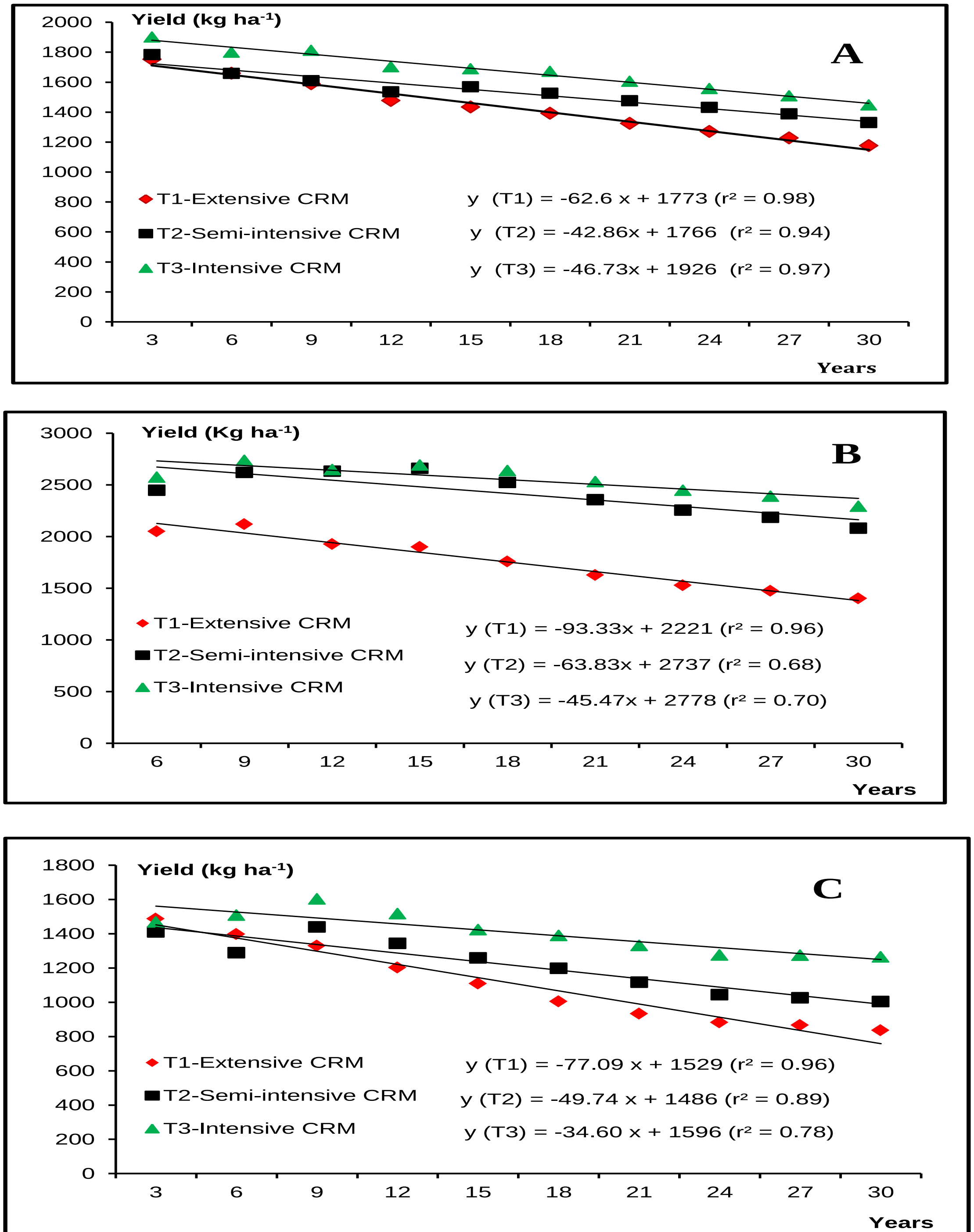

Figure 2: Evolution of crops yields during 30 years under crop residues management practices and fertilization at Boni; A) Seed cotton yields; B) Maize yields and C) Sorghum yields.

The low values of cation exchange capacity confers to these soils a poor capacity to maintain nutrients coming from soil mineralization or from inorganic manure applications (Babu et al., 2014; Nascente et al., 2015). It is known that CEC decline revealed chemical degradation of soil while the decline of both CEC and soil organic matter confirms the relations between these two parameters on lixisol (Pallo et al., 2009; Vanlauwe et al., 2015).

Recycling crop residues into compost or farmyard manure reduced significantly the losses of these two cations (Pallo et al., 2009). The effects of liming carried out in 1989 seem to be more beneficial on soil Ca^{2+} contents by its improvement. Beyond the direct effects on the solid phase of soil and the soil solution, liming is characterized especially by indirect effects on soil properties (Fabre and Kockmann, 2002; Vanlauwe et al., 2015).

Crop residues management effects on soil pH

Results showed that the variations of soil pH water and pH KCl were stastically significant after 30 years of continuous cropping for the three CRM treatments (Table 4). After six years, the pH water values highly decreased, requiring a liming in 1989 to solve this problem (Koulibaly, 2011; Cissé, 2013). After this liming and subsoiling in 1995, the effect of CRM showed few influence on pH which, after 25 years of continuous cropping, presented comparable values with those observed at the beginning of the study. However, various authors reported an influence of CRM on soil pH (Lemtiri et al., 2016). In addition, it was observed that $\triangle$pH values of 1 in average, particularly in the first and 30th years of soil exploitation represented an acidification induced by exchangeable aluminum (Yao-Kouamé, 2008; Vanlauwe et al., 2015).

Crop residues management and fertilizers effects on crops yields

The continuous cultivation of soil induced a decreasing pattern of crops yields, higher in extensive CRM than the other treatments (Figure 2). The low yields level in extensive CRM plots (T_1), using mainly inorganic fertilizers might be related to soil fertility decline intensity as well as the low efficiency of applied fertilizers (Omotayo and Chukwuka, 2009; Singh and Sidhu, 2014; Lemtiri et al., 2016).

However, recycling of crop residues in compost (T_2) and farmyard manure (T_3) improved soil properties, particularly by inducing a better availability of water and nutrients (Borie et al., 2002; Samra et al., 2003; Alam et al., 2014; Ouandaogo et al., 2016) which reduced yields decrease due to both the soil fertility decline and rainfall irregularity (Vullioud et al., 2004; Cissé, 2013; Nascente et al., 2015).

Conclusion

Continuous cropping led to the decline of soil chemical properties involving its degradation increase when crop residues are removed. Crop residues recycling and the use of compost or farmyard manures reduced yields decrease and the degradation of soil fertility, particularly, the decline of carbon content, exchangeable bases and CEC. The relative stability of pH during 30 years of continuous cultivation of soil is mainly related to the liming effects combined to regular application of rock phosphate revealed to be essential to prevent soil acidification.

In general, the crop residues incorporation influences soil biological activities and the availability of nutrients which need to be better specified. Due to early end of rainfall which often compromises incorporation of maize straws, a more suitable valorization should be considered for these residues as well as cotton straws whose burn is no longer acceptable. Moreover, the crop residues management and valorization of rock phosphate and the decline of soil fertility observed in this experiment suggested a reduction of the ploughing frequency for a better sustainability of this production system.

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