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Effects of crops residues management systems on crops yields and chemical characteristics of tropical ferruginous soil in Western Burkina Faso

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Crop residues' inappropriate management is the main constraint causing the decline in soil fertility and crop yields in Burkina Faso. This study was conducted at the Farako-Bâ Research Station from 2014 to 2019 to assess the effects of crop residue management to improve the sustainability of the cotton-cereal based production systems. The experimental design was complete randomized blocks of Fischer with four replications. Three different crop residue management practices were investigated: (i) Crop residue exportation and conventional tillage (T1); ii) Composted crop residues and conventional tillage (T2); and (iii) Crop residues used for soil mulching and no-tillage (T3). Soil chemical characteristics and crop yields were assessed as parameters in this study. Crop yields were improved by 17 to 34% on maize, from 18 to 38% on cotton and from 6 to 14% on sorghum, respectively, with residues recycled into compost (T2) and residues used for soil mulching (T3) compared to residues exported (T1). Crop residue management and soil tillage technics significantly increased the yields of maize, sorghum, and cotton after the first three years of experimentation. Soil chemical properties were not statistically influenced, except for SOM, nitrogen, and available K content. The highest decrease in soil carbon content induced by crop residue exportation (T1) should not be recommended to farmers.

Key words: Crop residues, tillage, soil fertility, cotton-cereals, yield, Burkina Faso.

INTRODUCTION

The new technologies' adoption in agriculture is based on their agronomic, socio-economic, and ecological advantages for farmers. In sub-Saharan Africa, the principles of conservation agriculture (CA) (minimum tillage, permanent soil cover, and crop rotation) have

been adopted for many years. Following these general principles, specific locally relevant practices have been developed on smallholder farms around the world to achieve sustainable intensification (Giller et al., 2015). Minimum or zero tillage has evolved considerably in sub-

Saharan Africa and demonstrates many benefits. However, this kind of agriculture is struggling to realize wider adoption despite its advantages highlighted by previous studies (Kanté, 2001; Djamen et al., 2015). Djamen et al. (2015) indicated that CA can be a sustainable intensification method for cropping systems. Though CA adoption increases the workload, their study showed evidence of increasing on-farm incomes. Ensuring farmers' sustainable productivity, including improvement and maintenance of favorable soil chemical properties, is a way to move towards good adoption of CA (Erenstein et al., 2012; Brown et al., 2017). The need to lead farmers away from current conventional practices is growing more urgent as these practices are rapidly degrading soil productivity and eroding the ability to maintain, or decrease, cotton and cereal production systems in sub-Saharan Africa (Ouattara et al., 2011; Obalum et al., 2012; Tully et al., 2015). Sustainable intensification goals will not be achieved with current practices.

Good management of crop residues can improve the sustainability of a production system (Bacye and Boro, 2011; Lemtiri et al., 2016). In this regard, agriculture in Sub-Saharan Africa is largely characterized by inadequate practices (Djamen et al., 2015; Lemtiri et al., 2016). In the farming systems of Burkina Faso, crop residues are mainly exported from the fields to provide animal feed because of insufficient access to quality grazing resources (Bacye, 1993; Bonde, 2007). Returning the crop residues to the soil, instead of exporting them as animal feed, improved the soil's physical, chemical, and biological characteristics. The benefits of this practice include improved soil organic matter (SOM), enhanced stability of aggregates, cation exchange capacity (CEC), and increased available nutrients in the soil (Blanco-Canqui and Lal, 2009). The use of crop residues to produce compost or to protect soil by mulching associated with zero tillage is among the technics recommended for achieving sustainable intensification goals in the Burkina Faso farming system.

In the cotton-growing areas of Burkina Faso, fertilization recommendations are based on the application of both organic and chemical fertilizers. To achieve cotton fertilization, the application of 2000 kg ha⁻¹ per year or 6000 kg ha⁻¹ every 3 years of compost is recommended to maintain soil organic status as well as mineral fertilizers by using NPK+S+B (150-200 kg ha⁻¹) and urea (50 kg ha⁻¹) (Ouattara et al., 2021). In addition to compost use, reducing tillage is also recommended in order to maintain soil structure and hasten SOM improvement (Vian et al., 2009). Another form of CA has subsequently evolved as an approach to direct sowing

under a mulch-based management system (DMC). This approach induces biomass production in the fields through the association of cover crops with cereals. However, CA is less widely adopted in cropping systems in sub-Saharan African countries due to the limited information available on its benefits.

The purpose of this study is to determine the effects of crop residue management and tillage practices on crops' productivity and soil chemical properties to improve the sustainability of cotton-zone production systems.

MATERIALS AND METHODS

Site description

The experiment was conducted at the Farako-Bâ Research Station located in Western Burkina Faso (04°20' W and 11°06' N; 450 m altitude). The climate of the site is sub-Saharan with an annual rainfall between 767 and 1332 mm for the study period from 2014 to 2019 (Table 1).

According to the FAO classification system, the soil of Farako-Bâ is a Lixisol with 12.90% of sand, 71.20% of silt, and 15.90% of clay. The pH water varied between 5.43 and 5.38, the organic matter from 0.97 to 0.82%, the total P from 118.90 to 109.61 mg kg⁻¹ and the total K from 746.25 to 733.82 mg kg⁻¹, respectively in the 0-10 and 10-20 cm layer depths (Table 2). This soil has a low exchangeable base content (1.54–1.40 cmol⁺ kg⁻¹ soil) and cation exchange capacity (2.94–3.01 cmol⁺ kg⁻¹ soil).

Plant material

Three cash crops (maize, sorghum, and cotton) and three cover crops were grown as plant materials in this study. Maize composite variety SR21 was used, with a 95-day cycle length (sowing-maturity) and a potential yield of 5000 kg ha⁻¹, and cotton FK37 was used, with a potential yield of 2500 to 3000 kg ha⁻¹ and a cycle length of 150 days. The variety of sorghum Sariasso 01, with a 120-day cycle length and a potential grain yield of 3000 kg ha⁻¹, was also cultivated. This variety is adapted to low rainfall conditions in the area from 400 to 700 mm (Table 1).

Cover crops used were *Brachiaria ruziziensis* (Congo Grass), *Crotalaria juncea* (Sunn Hemp), and *Cajanus cajan* (Pigeon Pea), with potential dry matter biomass production of 7000, 4500, and 10,000 kg ha⁻¹, respectively. These cover crops were associated with maize and sorghum to improve biomass production in the field (Table 1).

Treatments

The experimental design was complete randomized block with three treatments and four replications. Crop residue management combined with tillage practices studied were treatments defined below:

- T1. Exportation of crop residues + Conventional Tillage (CT)
- T2. Crop residues composted + Conventional Tillage (CT)

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Table 1. Crops sowing dates, rainfall and number of rainy days from 2014 to 2019.

Years	Crops	Sowing dates	Rainfall (mm)	Rainy days (days)
2014	Maize*	5 july	1191	79
2015	Cotton	22 june	1051	64
2016	Sorghum**	18 june	924	57
2017	Cotton	16 june	767	52
2018	Maize* +	11 june	1256	67
2019	Cotton	10 june	1323	73
Means			1085	65

* Cover crops (*Brach. Ruziziensis* + *Cajanus cajan*) sown 21 days after maize; ** Cover crops (*Brach. Ruziziensis* + *crotalaria juncea*) sown 21 days after sorghum.

Table 2. Soil chemical characteristics at 0-10 cm and 10-20 cm layers depths before experiment began (2014).

Chemical characteristics	0 - 10 cm	10-20 cm
pH _{water}	5.43	5.38
Soil organic matter (%)	0.97	0.82
N total (%)	0.05	0.04
C:N ratio	11.65	11.44
Total P (mg kg ⁻¹ soil)	118.90	109.61
Assimilable P (mg kg ⁻¹ soil)	6.48	6.06
Total K (mg kg ⁻¹ soil)	746.25	733.82
Available K (mg kg ⁻¹ soil)	136.52	126.97
Exchangeable bases (S) (Cmol ⁺ kg ⁻¹ soil)	1.54	1.40
Cation exchange capacity (Cmol ⁺ kg ⁻¹ soil)	2.94	3.01
Saturation content (V (%))	51.88	45.70

Table 3. Chemical characteristics of composts used in treatment T2.

Composts	Organic matter	N total	P ₂ O ₅	K ₂ O	CaO	C/N	pH
			%				
Compost/ residue of maize	45.49	1.49	0.28	2.09	1.212	17.72	8.36
Compost/ residue of sorghum	45.59	1.44	0.39	2.70	2.022	18.34	8.93
Compost/ residue of cotton	36.19	1.21	2.36	1.23	0.945	17.31	6.87

T3. Mulching of the soil (crop residues and cover crop biomass) + No Tillage (NT)

Biomass management (crop residues and cover crop biomass)

After the harvest of each grown cereal crop, the stalks of maize and sorghum are entirely exported from the plots (T1). However, for T2 treatment, cereal crop residues are transformed into compost that is used to fertilize the same plots on which the biomass was produced. The composted biomass quantities (maize or sorghum stalks) depend on the crops grown in the rotation.

On average, 5000 kg ha⁻¹ of compost was used per year. Table 3 shows the chemical characteristics of the composts used. The

composts content varied from 36.19 to 45.59 % of organic matter, 1.21 to 1.49 % of nitrogen, 0.28 to 0.39 % of P₂O₅, 1.23 to 2.70 % of K₂O, 2.214 to 0.95 to 2.02 % of CaO. The pH of the composts ranged from 7.52 to 9.07. In conventional tillage (CT), sowing is carried out on soil ploughed with oxen to a depth of 15 cm.

For T3 treatment, cover crops are grown in the row spacing of maize (*Brachiaria ruziziensis* and *Cajanus cajan*) and sorghum (*Brachiaria ruziziensis* and *Crotalaria juncea*) to improve biomass production (Table 1). Total biomass resulting from both cover crops and cereal crop residues is kept in mulch on the plot. Thus, cotton is grown in direct sowing under mulch cropping system (DMC) the next year after cultivation of maize or sorghum, which are also sown with no-tillage of soil. This treatment (T3) corresponds to direct sowing under a mulch cropping system (DMC).

Fertilization and crop protection

Mineral fertilization of maize and sorghum is done at 74N-36P-36K-12S-2B and 44N-27P-27K-9S-1.5B on cotton using NPKSB (14-18-18-6S-1B) applied 15 days after emergence and urea (46% N), at 40 days.

Cotton was protected against pests with indoxacarb (25.5 g ha⁻¹) at 30 and 44 days after emergence, a combination of profenofos (300 g ha⁻¹) + lambda cyhalothrin (18 g ha) at 58 and 72 days, and acetamipride (16 g ha⁻¹) and lambda cyhalothrin (15 g ha⁻¹) at 86 and 100 days.

Parameters measured

Crop yields and changes in soil chemical properties at 0–10 cm depth were measured over a six-year period (2014–2019). Soil chemical properties measured included pH, soil organic carbon (SOC), azote (N), phosphorus (P), potassium (K), exchangeable bases (Ca²⁺, Mg²⁺, K⁺, and Na⁺), cation exchange capacity (CEC), and the saturation rate. The different crop successions depending on the year are presented in Table 1.

The chemical analysis of the soil samples was carried out at the Soil-Water-Plant Laboratory of the Farako-Bâ research center. Soil pH was determined with a standard benchtop pH meter and electrode in a stirred slurry with a soil to distilled water ratio of 1 :2.5. The Walkley-Black (1934) method was used to determine SOC. A conversion factor of 1.724 was applied to SOC to calculate soil organic matter (SOM). The total N was obtained by the Kjeldahl method (Hillebrand et al., 1953). The ratio of C: N is obtained from the ratio of the carbon and nitrogen content of the soil. Total P was measured by open vessel digestion with sulfuric acid and colorimetric determination as per Anderson and Ingram (1989). Soil available P was determined by the method of BRAY 1 (Dickman and Bray, 1940). Total K was measured using a spectrophotometer and exchangeable potassium by the 1N ammonium acetate method at pH 7; magnesium and calcium exchangeable ions by a titrimetric method (Ethylene Diamine Tetra Acetic Acid). The exchangeable bases were obtained by the addition of Ca, Mg, K, and Na to the soil. Saturation rates correspond to the ratio of exchangeable bases and the exchange capacity of cations x 100.

Statistical analysis

Data on crop yields and soil chemical parameters such as organic matter, total N, total P and assimilable P, total K and available K, saturation rate, cation exchange capacity, and pH were collected and analyzed. The analysis of variance and standard deviations was performed using the XLSTAT 2016 version. Also, protected LSD test was employed as a post-hoc analysis for the comparison of the means ($\alpha = 0.05$) using XLSTAT software.

RESULTS AND DISCUSSION

Soil properties at the beginning of experimentation

In 2014, the chemical attributes of soil (Table 2), particularly the pH_{water} values at 0-10 cm and 10-20 cm layer depths, were 5.43 and 5.38, respectively, indicating that this soil was initially strongly acid according to Bunasols (1989). Previous studies in Farako-Bâ station (Bado, 2002; Koulibaly et al., 2014) revealed the soil acidity, which is mainly due to the lack of organic

restitution and the use of mineral fertilizers, as well as the cultivation of the soils and their progressive degradation.

Soil organic matter content was below 1%, while nitrogen values ranged between 0.04% and 0.05%. These low contents in this soil confirm the deficiencies of C and N highlighted by previous studies in most soils of Burkina Faso. These results are similar to those of the studies by Zombré (2006) and Ouandaogo et al. (2016), which indicate that soil organic matter degradation is generally caused by its mineralization and farmers' low organic restitution. According to Bunasols (1989) and Landon (1991), total phosphorus and potassium levels in the soil are considered "low", while available K values, which vary between 126.97 and 136.52 mg kg⁻¹, are considered "high" (Table 2). Initially, the soil had low exchangeable base reserves and CEC values, indicating a lack of chemical properties. According to Bacye et al. (2019) and Kaboré et al. (2021), inappropriate cultivation practices characterized by lack of restitution, destruction of soil structure and exposure, as well as climatic conditions, lead to a degradation of soil fertility.

Soil properties variation during the experimentation

Soil chemical characteristics variations between 2014 and 2019 (Table 4) revealed a decreasing trend. During this period, the SOM decrease was 22, 25, and 34%, respectively, with T3, T2, and T1 treatments. Crop residue management (compost or soil mulch) reduced soil organic matter losses compared to total residue exports associated with conventional tillage (N'Goran et al., 2012; Traoré et al., 2019). Organic restitutions by compost or mulching of soil, combined with minimum tillage, are important approaches to reduce SOM and nutrient losses from crops. These results confirm the role and importance of organic restitutions (Coulibaly et al., 2020; Bacye et al., 2021). The chemical characteristics of the soil after 6 years of production show that the export of residues associated with conventional tillage increases soil nutrient losses through runoff and leaching, in contrast to soil cover and recycling, which ensure a partial restitution of losses linked to crop exports (Razafimbelo et al., 2006; Ouattara et al., 2018).

The total N content, which was 0.05% in 2014, decreased by 20, 24, and 30%, respectively, with T3, T2, and T1 in 2019 (Table 4). Soil nitrogen losses were reduced by no tillage, soil mulching treatment (T3), and recycling of crop residues into compost (T2), according to Baruah and Baruah (2015). Mulching with leguminous cover crops such as *Crotalaria retusa* and *Cajanus cajan* reduced nitrogen losses through erosion and leaching of NO (Smith et al., 1987; Meisinger et al., 1991).

From 2014 to 2019, total P losses were 78.21, 52.06, and 65.75 mg/kg soil, respectively, with T1, T2, and T3 treatments. Residue management practices (recycling and mulching) reduced soil P losses. In contrast

Table 4. Variation of soil chemical characteristics at 0-10 cm layer depth from 2016 to 2019.

Treatments	SOM		Total N		Total P		Available P		Total K		Available K		S		CEC		pH water	
	2016	2019	2016	2019	2016	2019	2016	2019	2016	2019	2016	2019	2016	2019	2016	2019	2016	2019
	%		%		mg kg ⁻¹		mg kg ⁻¹		mg kg ⁻¹		mg kg ⁻¹		cmol ⁺ kg ⁻¹		cmol ⁺ kg ⁻¹			
T1: Exportation + CT	0.70 ^a ±0.07	0.640 ^b ±0.08	0.040 ^a ±0.00	0.035 ^b ±0.003	151.83 ^a ±25.50	73.62 ^a ±15.02	5.08 ^a ±1.22	6.91 ^a ±3.07	612.83 ^a ±168.72	785.73 ^a ±98.30	71.92 ^b ±14.91	66.02 ^c ±11.02	1.80 ±0.29	1.48 ±0.39	2.93 ±0.47	2.44 ±0.64	5.67 ^a ±0.21	5.56 ^a ±0.33
T2: Compost + CT	0.70 ^a ±0.12	0.730 ^{ab} ±0.09	0.040 ^a ±0.00	0.038 ^{ab} ±0.004	132.79 ±22.79	80.73 ^a ±18.27	5.39 ^a ±1.51	9.95 ^a ±4.74	533.91 ^a ±155.21	831.82 ^a ±135.55	73.73 ^b ±10.93	89.31 ^b ±15.61	1.85 ±0.40	1.65 ±0.45	3.11 ±0.70	2.58 ±0.62	5.69 ^a ±0.23	5.60 ^a ±0.35
T3: Mulch + NT	0.78 ^a ±0.12	0.761 ^a ±0.08	0.040 ^a ±0.01	0.040 ^a ±0.004	141.57 ±20.72	75.82 ^a ±15.89	6.20 ^a ±1.67	5.54 ^a ±1.69	586.14 ^a ±122.68	889.29 ^a ±65.79	91.22 ^a ±3.61	123.09 ^a ±20.31	2.34 ±1.09	1.74 ±0.38	3.32 ±1.22	2.57 ±0.49	5.62 ^a ±0.42	5.77 ^a ±0.19
Probability (α = 0.05)	0.508 (ns)	0.033 (s)	0.182 (ns)	0.041 (s)	0.344 (ns)	0.691 (ns)	0.477 (ns)	0.127 (ns)	0.637 (ns)	0.329 (ns)	0.046 (s)	0.000 (s)	0.318 (ns)	0.548 (ns)	0.712 (ns)	0.884 (ns)	0.904 (ns)	0.540 (ns)

SOM: Soil organic matter; CT: Conventional tillage, NT: No Tillage. Means with the same letters indicate no significant difference as compared using Protected LSD (α = 0.05).

to total P, available P levels were improved after 6 years of production with residue export (T1) and recycling of crop residues into compost. Although statistically homogeneous after 6 years of production, the recycling of crop residues into compost or used as mulch provided the best total K (297, 91, and 303.15 mg kg⁻¹ soil) and the available K (15.58 and 31.87 mg kg⁻¹ soil) balances compared to exporting all residues (Dakouo, 1994; Armand et al., 2021). Progressive degradation of organic matter, which is more pronounced in tropical regions, would have contributed to maintaining and improving soil P and K levels.

Although statistically equal in 2016 and 2019, soil exchangeable bases and cation exchange capacity decreased when compared to the original state of the soil in 2014, even if a small reduction in exchangeable bases (11 to 26%) and CEC (17 to 23%), which is more pronounced with mulch (T3) than with residue export (T1), were observed (Table 4). According to Bednarz

et al. (1998); FAO (2006), these decreases were linked to soil organic matter levels.

Crop yields variation

Crop residue management (mulch and compost) improved crop yields significantly from the fourth year of production (Table 5). These yield increases related to organic restitution in the form of compost or mulch are in the order of 18–38% on cotton yield, 6–14% on sorghum yield, and 17–34% on maize yield, respectively, with residue recycling in compost (T2) and soil cover under mulch (T3) compared to residue export (T1) (Koulibaly et al., 2016; Traore et al., 2021; Nyagorme et al., 2021).

Conclusion

This study showed the benefits of organic

restitution in any form influence crop yields and soil chemical properties. Like the recycling of crop residues into compost, the production of biomass by combining cover crops with cereals and using them as a soil cover reduces soil nutrient losses. This practice, which is a faithful reflection of cover cropping systems, needs to be further explored in order to offer producers an alternative for sustainable soil fertility management.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Table 5. Yields of maize, sorghum and cotton during the study from 2014 to 2019.

Treatment	2014	2015	2016	2017	2018	2019
	Maize	Cotton	Sorghum	Cotton	Maize	Cotton
	kg ha⁻¹					
T1. Exportation + CT	2471 ^a	1253 ^a	2128 ^a	1293 ^b	1521 ^b	1060 ^b
T2. Compost + CT	2607 ^a	1476 ^a	2434 ^a	1961 ^a	2477 ^a	1541 ^a
T3. Mulch + NT	2529 ^a	1416 ^a	2262 ^a	1419 ^{ab}	2015 ^{ab}	1381 ^{ab}
F	0.106	1.548	3.008	5.294	3.387	3.980
Probability ($\alpha = 0.05$)	0.900 (ns)	0.245 (ns)	0.080 (ns)	0.016 (s)	0.010 (s)	0.38)

CT: Conventional tillage, NT: No Tillage. Means with the same letters indicate no significant difference as compared using protected LSD ($\alpha = 0.05$).

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