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On-Station and On-Farm Assessment of the Effects of Soil Cover on Conservation Agriculture Performances in Western Burkina Faso

Kalifa Coulibaly[1,2*], Baba Ouattara[3], Souleymane Ouédraogo[3], Nadine Andrieu[4], Hassan B. Nacro[1]

[1]Laboratoire d'Etude et de Recherche et sur la Fertilité du sol (LERF), Institut du Développement Rural (IDR), Université Nazi BONI (UNB), Bobo-Dioulasso, Burkina Faso
[2]Centre International de Recherche Développement sur L'élevage en Zone Subhumide (CIRDES), Bobo-Dioulasso, Burkina Faso
[3]Institut de l'Environnement et de Recherche Agricole (INERA), Ouagadougou, Burkina Faso
[4]Centre de Coopération Internationale en Recherche Agronomique Pour le Développement (CIRAD), Montpellier, France
Email: *kalifacoul1@yahoo.fr, nacrohb@yahoo.fr, babaouattara2005@yahoo.fr, osilamana@yahoo.fr, nadine.andrieu@cirad.fr

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Abstract

Conservation agriculture (CA) is one option for dealing with such a challenge, but its main difficulty in West Africa is in maintaining permanent soil cover, particularly with crop residues, due to their preferential use for livestock fodder. The aim of our study was to determine the effect of crop residue mulching on the efficiency of cropping systems based on the principles of conservation agriculture. The experimental design was based on on-station experiments, intended to assess the specific effect of different levels of crop residue mulching on the biological and chemical soil fertility parameters, while in on-farm experiments we mainly assessed the ability of farmers to actually collect crop residues for soil cover and the associated effects on weeds and yields. The on-station experimental design was in fully randomized factorial blocks comprising five treatments and three replicates. The treatments compared the conventional system, tillage and cropping without mulching, and CA systems with 1 ton, 2 tons, and 4 tons of straw per hectare in plots of 10 m^2. The effects of CA on the macrofauna, respiratory activity, and soil chemical parameters were evaluated in the 2014 and 2015 growing seasons. For the on-farm experiments, the conventional and CA practices of 15 farmers were compared to conventional practices in 2013 and 2014 in plots of 626 m^2. The on-station results showed that the presence of crop residue mulching induced an increase in the density of termites. A significant release of carbon dioxide (CO_2) in the CA treatments compared to the conventional treatment was also observed. For the chemical parameters (pH, N, P and K) were significantly and positively affected by mulch in the top 5 centimeters of soil. The on-farm experiments confirmed the difficulty of farmers in collecting enough biomass, with negative effects on grass cover leading to generally lower yields than conventional treatments. Other practices also affected the results, such as the maize sowing date, the gap between sowing and weeding, the gap between sowing and urea supply, the number of years of CA practices in the plot and, the gap between maize sowing and cowpea sowing. For the farmers having the human resources to collect enough crop residues for soil cover and follow the steps of the crop management sequences, it was possible to maintain yields compared to the conventional practice.

Keywords

Mulching, Macrofauna, Soil Respiratory Activity, Chemical Fertility, Conservation Agriculture

1. Introduction

Agricultural soils in West Africa are characterized by poor structural stability of the surface horizons, low silt and clay content, low organic matter (typically less than 3% under natural vegetation and 0.7% under crops), and low nutrient content [1] [2].

In the past, agricultural land management systems in West Africa involved the extensive cultivation of crops for 3 to 5 years followed by a fallow period of at least 10 years [1] [3] [4]. This practice helped to maintain soil fertility. Nowadays, due to a strong demographic pressure on land (3.1% annual increase of population in Burkina Faso, according to INERA [5], this traditional management system is disappearing, leading to an increase in cultivated areas to the detriment of grazing and fallow areas [6]. Despite this expansion of croplands, crop residues, which play a key role in fodder supplies of cattle, remain insufficient to feed the growing numbers of animals [7] [8].

The practice of low-input agriculture accentuates soil degradation in this region [9]. About 65% of croplands in the region have been degraded over the last 40 years [10] [11] [12]. Such degradation leads to a decrease in the chemical, physical and biological fertility of the soil, threatening food security. In Burkina Faso, it is estimated that about 24% of arable land is severely degraded [13].

New practices are therefore promoted by research and development organizations for the sustainable improvement of crop productivity and food security of rural households.

These new practices are mainly based on Soil and Water Conservation (SWC), and Conservation Agriculture (CA). SWC practices involve the construction of erosion control structures at right angles to the slope to slow down water runoff and reduce soil erosion [14]. Conservation Agriculture is based on three principles, namely, minimal soil disturbance, permanent soil cover with live or dead plant mulch (straw) and rotations and/or associations of crops [15]. Several studies have shown the benefits of CA practices compared to tillage-based conventional agriculture in enabling sustainable improvement of soil productivity [16], [17] [18]. The practice of CA can increase the organic matter content in soil [19], and enhance soil biological activity [20] [21], which helps to improve soil structure and crop yields after several years of practice [22]. For [21], conservation agriculture, which enhances soil biodiversity, is a departure from agricultural intensification.

Despite these potential benefits, adoption rate of CA is low in Africa [23]. The main challenge for farmers is to maintain crop residues on the soil surface, since they are preferentially used for animal feeding [24] [25]. On the other hand, it has been shown in other regions that even low amounts of biomass for soil cover can have positive effects on soil fertility and crop yields [19]. Another challenge wit CA is weed infestation. Tillage is often used to control weeds, whilst has shown that high amounts of surface residues are needed to reduce weed emergence and growth [26].

The first trials on CA systems in West Africa took place in the late 1960's [22]. However, since then few trials have been conducted and they did not allow to assess the quantity of straw needed for soil cover in CA systems. A specific challenge for research in West Africa is to identify in how far whether it is possible to partition crop residues for animal feeding and for soil cover by characterizing the amount of crop residue mulching that leads to improved CA cropping system performances.

The objective of this paper was to analyze how different amounts of surface crop residue mulching affect CA performance. This study was conducted in western Burkina Faso, which is the agricultural breadbasket of the country, and where CA is new. In western Burkina Faso, maize, sorghum, and cowpea are the main crops grown for household consumption, with the surplus being sold. Cotton is the main cash crop. For maize, the conventional practice is based on single cropping and the application of chemical (150 kg per ha of NPK) and organic (2 t per ha) fertilizers.

It combined on-station experiments with on-farm experiments to analyze farmers' ability to collect enough crop residues, and the associated effects on yields and weeds. After presenting the experimental framework, we assess the effects, on-station and on-farm, of different amounts of straw cover on CA efficiency compared to the conventional practice.

2. Materials and Methods

2.1. Study Site

The on-station experiment was conducted at the experimental station of the International Centre for Research and Development on Livestock in Sub-humid zones (CIRDES), in the village of Banankélèdaga (10˚11'N and 4˚06'W; 300 m).

Banankélédaga is located about fifteen kilometers from Bobo-Dioulasso on the Bobo-Dioulasso-Faramana road (**Figure 1**). The climate is characterized by a wet season from May to October and a dry season from November to April [27]. The rainfall recorded in 2014 and 2015 was 937 and 915 mm, respectively. The natural vegetation of Banakélédaga comprises woody shrubs and grasses. The soils are lixisols. They have a sandy to clay-sandy texture that is prone to nutrient leaching causing loss of soil fertility [28].

The on-fam experiments were conducted in Koumbia (3˚41'15"W; 11˚14'47"N), a village located in the same agro-ecological zone, at about 60 km from Bobo-Dioulasso. In this village, maize occupies 55% of the village's total cereal cropping area. The rainfall recorded in 2013 and 2014 cropping seasons was 841.8 and 965.5 mm, respectively.

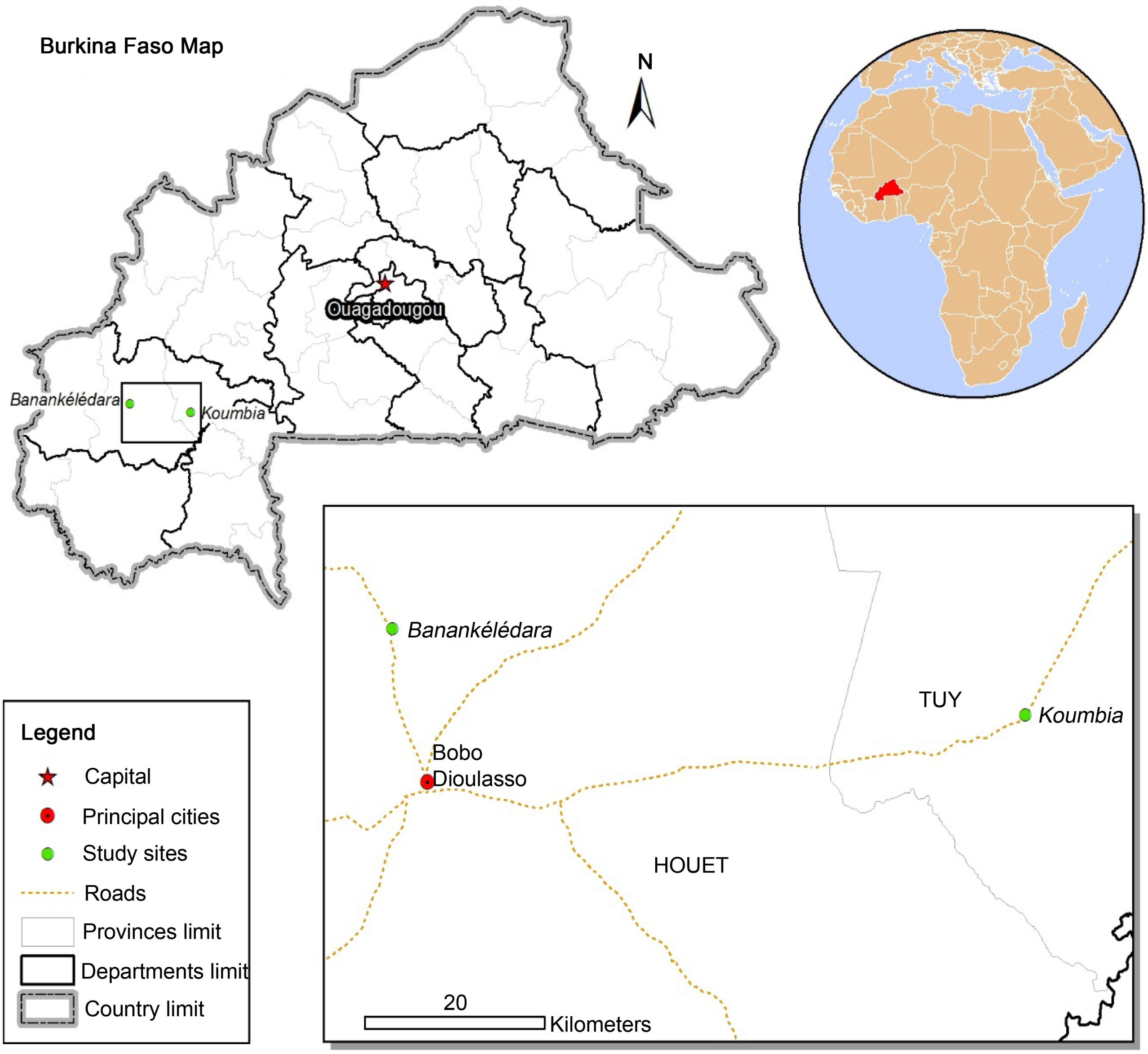


Figure 1. Location of the study sites.

2.2. On-Station Experiment

2.2.1. Experimental Setup

The experiment was installed in 2012. The experimental design was a fully randomized factorial block with five treatments and three replications. The treatments were: T_0: Plowing of maize + 0 t ha^{-1} of crop residues (control), T_{0t}: Direct sowing of maize/cowpea + 0 t ha^{-1} of crop residues, T_{1t}: Direct sowing of maize/cowpea + 1 t ha^{-1} of crop residues, T_{2t}: Direct sowing of maize/cowpea + 2 t ha^{-1} of crop residues, T_{4t}: Direct sowing maize/cowpea + 4 t ha^{-1} of crop residues.

Plot size was 10 m × 10 m separated by an alley of 1 m, while rehearsals were remote blocks of 2 m.

T_0 treatment consisted of flat Plowing with removal or incorporation of the residues, whereas in the other treatments soil was were covered by 1, 2 or 4 tons per hectare of crop residues (maize and sorghum straw). Herbicide (RoundUp) was applied at a dose of 1 L ha^{-1} in all plots before planting. Maize (*Zea mays* L.), variety SR21 intermediate cycle (110 days), was sown in 2014 and 2015 in all plots at a spacing of 40 cm between planting holes and 80 cm between rows. The SR21 maize variety was chosen because it is widely used by farmers in the area. The KVX442 cowpea variety *(Vigna unguiculata* L. Walp*)* was sown 30 days after maize and following the same spacing between the maize rows. The choice of this variety of cowpea was because its short cycle (67 days) and its production of fodder. For maize, 150 kg ha^{-1} of NPK compound fertilizer (15-15-15) was applied on the 15th day after sowing (DAS). Fifty kg ha^{-1} urea (46% nitrogen) was also applied on maize in two split applications on the 30th and 45th DAS. The fertilizer rates used were those recommended by research for the cultivation of maize in Burkina Faso. All the plots were weeded twice at 15 and 40 DAS in 2014 and 35 and 90 DAS in 2015. The insecticide K-Optimal was applied to cowpea at the flower bud and pod formation stages.

2.2.2. Measurements

The TSBF method (Tropical Soil Biology and Fertility) was used for the inventory of soil macrofauna [29]. A portion of soil of 15 cm × 15 cm × 2 cm was extracted with a metal frame was spread on a bag and the macrofauna was collected. Termites, earthworms and millipedes were counted. The inventory was conducted on the 45th and 90th day after sowing (DAS). It was done over two days and entirely in the morning (before 11 am) to avoid individual organism moving downwards because of the sun.

The respirometry analysis consisted in collecting a hundred grams of soil, sieved to 2 mm, and moistened to 2/3 of the maximum retention capacity of each treatment [30]. The soil was then placed in two sealed jars. Two vials, one containing sodium hydroxide (0.1 N NaOH) for trapping the CO_2 released and the other one containing distilled water to maintain constant moisture, were placed in each jar. The jar was then placed in an oven controlled at 28˚C for 14 days. The amount of CO_2 released was measured daily for the first 8 days of incubation, then every two days daily until the 14th day. The CO_2 released during the study was trapped by the sodium hydroxide (NaOH, 0.1 N) and precipitated as sodium carbonate by 3% barium chloride. Sodium hydroxide (NaOH) in excess was neutralized with hydrochloric acid (0.1 N HCl) in the presence of phenolphthalein. The amount of CO_2 released per day was expressed in mg. 100 g soil^{-1} sec and given by the following formula [30]:

$$Q(\text{mg}) = [\text{VHCl}(\text{control}) - \text{VHCl}(\text{treatment})] \times 2.2$$

VHCl (control) is the average volume of hydrochloric acid for the control,

VHCl (treatment) is the average volume of hydrochloric acid for the treatment,

The coefficient 2.2 indicates that 2.2 mg of CO_2 corresponds to 1 ml of HCl (0.1 N).

Soil was sampled after harvest from the 0 - 5 cm (in 2015) and 0 - 20 cm (in 2014 and 2015) soil layers. The composite sample from three sampling points along a diagonal of each unit plot was dried in the shade and sieved to 2 mm. The analyses were carried out in the Farako-Ba (Burkina Faso) laboratory of the environmental and agricultural research station. pH water and KCl was measured with a pH meter glass electrode by the electrometric method with a soil/solution ratio equal to 1/2.5 [31]. The carbon content was determined by the method of Walkley-Black [32]. The total nitrogen and total phosphorus contents were determined by attacking the soil samples by the KJELDALH method [33] followed by assays by the SKALAR autoanalyzer (automatic colorimetry). Available phosphorus was extracted by the Bray method [34]. Total potassium was determined using a flame photometer after mineralization of soil samples with a hot concentrated sulfuric acid solution in the presence of a catalytic core. Exchangeable bases were extracted using a solution of ammonium acetate and then assayed by atomic absorption spectrophotometry.

2.3. On-Farm Experiments

2.3.1. Experimental Setup

Fifteen (15) farmers who carried out previous CA trials in 2013 and received training in CA principles were selected for the experiment. The experiments were carried out in 2014 and 2013 on 15 plots. This gave us 30 plots of experiments over the 2 years. The farmers' plots were blocks or replications divided into 2 basic plots of 625 m^2 (**Figure 2**).

The theoretical technical itinerary that has been selected is presented in the box below.

1) Ploughing the control plots as soon as the first useful rains arrive.

2) CA plots are covered with residues (straw, shrub foliage, etc.) and are not ploughed.

3) Sow the maize manually on the plots at the following spacings:
row spacing 80 cm and inter-sowing pot 40 cm (1 to 3 seeds per poquet).

Continued

4) Apply pre-emergence herbicide to the plots at the rate of 2 l/ha.
5) Sow cowpea manually on the CA plots in the inter-row maize with a distance of 40 cm; this should be done 15 to 20 days after sowing the maize.
6) Perform mechanical and manual weeding 15 to 20 days after sowing on the control plots and manual weeding only on the CA plots.
7) Apply the NPK (15 15 15) at 150 kg/ha 15 to 20 days after sowing (on CA plots).
8) Apply urea (46% N) at a rate of 50 kg/ha 35 to 40 days after sowing on all plots.
9) Carry out the ridging on the control plot and only after urea has been added.
10) Harvest maize and cowpea after yield measurements and in such a way as to retain residues on the CA plots.
11) Ensure the protection of residues during the dry season according to a method you have chosen.

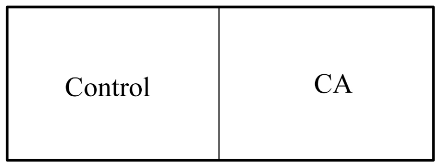


Figure 2. On-farm expérimental design. Control: tillage + maize (conventional system). CA: mulching + maize + cowpea.

2.3.2. Measurements

The amount of biomass used for soil cover was determined by measurements before sowing. To do this, 3 plots of 1 m^2 each were positioned randomly in each CA plot. This biomass, which weighed between 0 and 18 t/ha of dry matter, consisted of the crop residues produced the previous cropping season in the same plots and of various additional inputs (shrub biomass, native hull remains, etc.) according to the farmers' abilities and strategies for obtaining the biomass. Data on the crop management sequences (dates of sowing, weeding, and fertilizer application, stocking densities) were collected by interviewing farmers during the cropping season.

Observations of the grass cover in plots were made at two distinct times (15-20 DAS and 45-55 DAS). Weed cover was rated on the scale of 1 to 9 of the *Biological Testing Commission* [35]. Measurements were taken in the 15 plots in both 2013 and 2014.

For yield measurements, 3 plots of 12 m^2 (3 m × 4 m) were randomly positioned in the plots of each treatment to determine grain and forage yields of the crops. Measurements for maize were carried out in all plots in 2013 and 2014. For cowpea, only stalk yields could be measured in 14 plots in 2013. In 2014 cowpea stalk yields were measured in 12 plots and cowpea grain yields in 10 plots. This is because the maturity of cowpea is staggered over time and some farmers harvested before yield measurements.

2.4. Statistical Analysis of the Data

An analysis of variance (ANOVA) was done with XLSTAT 07/09/00 and means were compared at the 5% level according to the Fisher test. The analysis concerned the chemical and biological parameters of the soil in the on-station experiment.

The multivariate analysis method was used to highlight the diversity of farming practices in the field experiments. A Principal Component Analysis (PCA) was carried out on the biomass (mulching) data, crop management sequences and weed control of the CA treatment for the 30 plots. The variables related to maize yields and the year of the experiment were considered as additional variables. The PCA identified variables that mostly contributed to variability between farmers' practices. A hierarchical ascendant classification (HAC) was then carried out using the coordinates of the observations on the factorial axes obtained from the PCA. This made it possible to form classes of homogeneous cultural practices. Table 1 gives the list of variables used. Analyses of variance (ANOVA) were performed to compare treatments (Control and CA) within each class. For the ANOVAs, the Fisher test compared the averages at the 5% threshold. XLSTAT 2015.4.01 software was used.

Table 1. List of variables used.

Variables names	Unit	Description
Biomass	kg/ha	quantity of straw used for soil cover in CA
Nb Ye CA	numeric	number of years of CA practice on the plot
SOW Maize	numeric	maize sowing date expressed in number of days of the year
Gap Ma-Cow	numeric	number of days between maize sowing and cowpea sowing
Sow-Weed	numeric	number of days between sowing and weeding
Sow-Npk	numeric	number of days between sowing and NPK application
Sow-Urea	numeric	number of days between sowing and Urea application
Grass-15 DAS	percentage	grass cover rate of plots 15 - 20 days after sowing
Grass-45 DAS	percentage	grass cover rate of plots 45 - 55 days after sowing
Density	plants/ha	maize density per hectare
Grain	kg/ha	maize grain yield per hectare
Straw	kg/ha	maize straw yield per hectare
Year	numeric	experimentation year

3. Results

3.1. On-Station Experiment

3.1.1. Effect of Conservation Agriculture on Soil Macrofauna

The most represented group was the termites with proportions varying between 90% (T_{4t}) and 98% (T_{2t}) in 2014 and between 50% (T_0) and 87% (T_{4t}) in 2015. The termite group was followed by the earthworm group and the millipede group.

The results of 2014 showed that the CA treatments had, in general, a higher macrofauna density whatever the sampling period (Table 2). Forty-five DAS, we recorded a total density (termites, earthworms and millipedes) of 4378, 1748, 637 and 630 individuals m^{-2} for T_{4t}, T_{2t}, T_{1t} and T_{0t}, respectively, as opposed to 141 individuals m^{-2} for T_0. At 90 DAS, the total density of the same species was 985, 2956, 2044 and 2126 individuals m^{-2} for T_{4t}, T_{2t}, T_{1t} and T_{0t}, respectively, as opposed to 341 individuals m^{-2} for T_0.

In 2015, we observed the same trend 45 DAS with 649, 422, 316 and 304 individuals m^{-2} for T_{4t}, T_{2t}, T_{1t} and T_{0t}, respectively, as opposed to 99 individuals m^{-2} for T_0 (Table 3). At 90 DAS, the total density of species was 405, 296, 172, and 84 individuals m^{-2} for T_{4t}, T_{2t}, T_{1t} and T_{0t}, respectively, as opposed to 136 individuals m^{-2} for T_0.

Except for the termite group 45 DAS in 2014, the difference observed between the treatments was not significant (5% level) for all groups of macrofauna studied 45 and 90 DAS in 2014 and 2015.

Table 2. Effect of conservation agriculture on soil macrofauna density (Number ind./m^2) at 45 and 90 days after seeding (DAS) in 2014.

	Macrofauna at 45 DAS			Macrofauna at 90 DAS		
	Density termites	Density earthworm	Density millipede	Density termites	Density earthworm	Density millipede
T_0	$111.11^a \pm 76.98$	7.41 ± 12.83	22.22 ± 0.00	325.93 ± 323.81	14.82 ± 25.66	0.00 ± 0.00
T_{0t}	$585.19^a \pm$ 711,23	22.22 ± 0.00	22.22 ± 22.22	2059.26 ± 2127.93	59.26 ± 33.95	7.41 ± 12.83
T_{1t}	$614.82^a \pm 741.81$	14.82 ± 25,66	7.41 ± 12.83	2000.00 ± 2465.26	29.63 ± 25.66	14.82 ± 12.83
T_{2t}	$1666.67^a \pm 1444.96$	22.22 ± 0.00	59.26 ± 46.26	2888.89 ± 3314.84	44.44 ± 38.49	22.22 ± 22.22
T_{4t}	$4237.04^b \pm 2188.00$	59.26 ± 51.32	81.48 ± 102.64	888.89 ± 101.84	51.85 ± 51.32	44.44 ± 44.44
ddl	4	4	4	4	4	4
Probability	0.016	0.218	0.424	0.599	0.595	0.259
Signification	S	NS	NS	NS	NS	NS

Fisher test at 5%: 1) the difference is not significant between the values assigned by the same letter in the same column; 2) each value is the average of 3 repetitions; 3) S: Significant; NS: Not Significant. Legend: T_0: Plowing of maize + 0 t ha^{-1} of crop residues (control), T_{0t}: Direct sowing of maize/cowpea + 0 t ha^{-1} of crop residues, T_{1t}: Direct sowing of maize/cowpea + 1 t ha^{-1} of crop residues, T_{2t}: Direct sowing of maize/cowpea + 2 t ha^{-1} of crop residues, T_{4t}: Direct sowing maize/cowpea + 4 t ha^{-1} of crop residues.

Table 3. Effect of conservation agriculture on soil macrofauna density (Number ind./m^2) at 45 and 90 days after seeding (DAS) in 2015.

	Macrofauna at 45 DAS			Macrofauna at 90 DAS		
	Density termites	Density earthworm	Density millipede	Density termites	Density earthworm	Density millipede
T_0	69.13 ± 52.03	14.81 ± 0.00	14.81 ± 0.00	69.13 ± 37.28	44.44 ± 0.00	22.22 ± 10.47
T_{0t}	251.85 ± 142.32	37.03 ± 0.47	14.81 ± 0.00	44.44 ± 41.90	24.69 ± 8.55	14.81 ± 0.00
T_{1t}	197.53 ± 123.36	29.62 ± 5.67	88.89 ± 0.00	103.70 ± 64.57	14.81 ± 0.00	59.26 ± 0.00
T_{2t}	340.74 ± 51.32	44.44 ± 9.20	37.04 ± 31.43	162.96 ± 108.23	74.07 ± 0.00	59.26 ± 0.00
T_{4t}	567.90 ± 51.32	59.26 ± 0.00	22.22 ± 10.47	350.61 ± 238.11	24.69 ± 8.55	29.63 ± 0.00
ddl	4	4	4	4	4	4
Probability	0.145	0.462	0.462	0.166	0.198	0.164
Signification	NS	NS	NS	NS	NS	NS

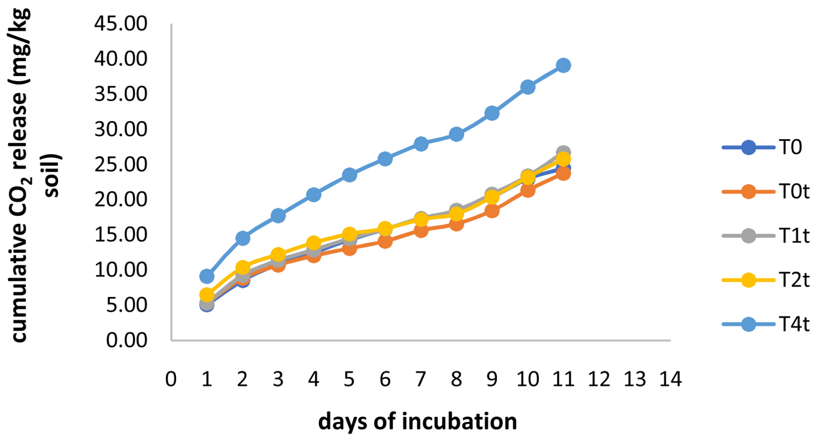
Fisher test at 5%. 1) each value is the average of 3 repetitions; 2) NS: Not Significant. Legend: T_0: Plowing of maize + 0 t ha^{-1} of crop residues (control), T_{0t}: Direct sowing of maize/cowpea + 0 t ha^{-1} of crop residues, T_{1t}: Direct sowing of maize/cowpea + 1 t ha^{-1} of crop residues, T_{2t}: Direct sowing of maize/cowpea + 2 t ha^{-1} of crop residues, T_{4t}: Direct sowing maize/cowpea + 4 t ha^{-1} of crop residues.

3.1.2. Effect of Conservation Agriculture on Soil Respiratory Activity

Changes in cumulative amounts of CO_2 during the 14 days of incubation are shown in Figure 3. There was an increase in CO_2 production accumulated for all treatments. In general, in 2014, after 4 days of incubation T_{4t} induced the greatest soil carbon mineralization. In 2015, the cumulative release of CO_2 was higher for the CA treatments (T_{0t}, T_{1t}, T_{2t}, T_{4t}) compared to the control treatment (T_0). There was also a decrease in the release of CO_2 when the amount of straw increased ($T_{4t} < T_{2t} < T_{1t} < T_{0t}$). However, statistical analyses of cumulative amounts of CO_2, revealed no significant difference between treatments in 2014 or in 2015.

3.1.3. Effect of Conservation Agriculture on Soil Chemical Properties.

The results of 2014 showed that the chemical characteristics between the different treatments were generally statistically similar except for T_{4t} (Table 4). The pH values (pH_H_2O and pH_KCl) obtained showed that the soils were slightly acidic. These values were significantly higher for T_{4t} compared to the other treatments at the 5% probability level. The variance analysis for total nitrogen or total potassium gave statistically different results, characterized by high rates for T_{4t}. These rates were low for T_0 but also for T_{2t}, T_{1t}, and T_{0t}. The carbon content was somewhat similar between treatments except for T_{4t} where rates were higher without being significant ($p < 0.05$). The results were also not significant ($p < 0.05$) between treatments for phosphorus values (total and available). The lowest observed rates were those for the T_{0t} treatment compared to the other treatment rates. T_{4t} and T_0 had the highest rates.



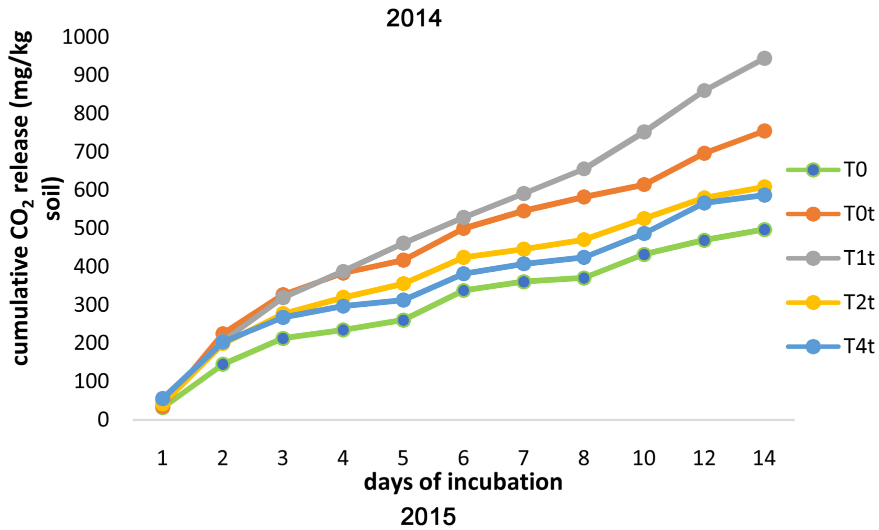


Figure 3. Cumulative evolution of CO_2 released according to the different treatments (each point is the average of 3 repetitions). Legend: T_0: Plowing of maize + 0 t ha^{-1} of crop residues (control), T_{0t}: Direct sowing of maize/cowpea + 0 t ha^{-1} of crop residues, T_{1t}: Direct sowing of maize/cowpea + 1 t ha^{-1} of crop residues, T_{2t}: Direct sowing of maize/cowpea + 2 t ha^{-1} of crop residues, T_{4t}: Direct sowing maize/cowpea + 4 t ha^{-1} of crop residues.

In 2015, in the 0 - 5 cm soil horizon, the statistical analysis showed no significant differences at the 5% threshold regarding pH KCl, carbon, C/N, and available phosphorus (**Table 5**). On the other hand, the pH_H_2O, nitrogen, total phosphorus and total potassium values were statistically different between treatments. Treatment T_{4t} had higher values for pH_H_2O (5.39), pH_KCl (4.82), carbon (0.55%) and nitrogen (0.05%) compared to the other treatments (T_{2t}, T_{1t}, T_{0t} and T_0). The results found for the 0 - 20 cm soil horizon were only significant for total potassium.

3.2. On-Farm Experiments

3.2.1. Diversity of CA Practices between Farmers

Figure 4 shows that the factorial plane, consisting of the F1 and F2 axes, accounted for 43% of the variability. The square cosine of the variables shows that

Table 4. Effect of conservation agriculture on soil chemical parameters in 2014.

	pH_H$_2$O	pH_KCl	C (%)	N (%)	C/N	P_total (mg/kg soil)	P_ass. (mg/kg soil)	K_total (mg/kg soil)
T_0	$5.58^a \pm 0.35$	$4.38^a \pm 0.36$	0.51 ± 0.10	$0.043^b \pm 0.008$	11.83 ± 0.97	89.91 ± 14.13	3.04 ± 1.86	$832.99^{ab} \pm 194.45$
T_{0t}	$5.61^a \pm 0.38$	$4.38^a \pm 0.42$	0.47 ± 0.09	$0.038^a \pm 0.005$	12.11 ± 0.87	77.67 ± 5.57	2.38 ± 1.64	$787.63^a \pm 174.13$
T_{1t}	$5.66^a \pm 0.34$	$4.45^a \pm 0.38$	0.51 ± 0.10	$0.043^b \pm 0.007$	11.85 ± 0.98	84.08 ± 8.28	2.64 ± 1.87	$887.85^b \pm 201.94$
T_{2t}	$5.65^a \pm 0.23$	$4.32^a \pm 0.31$	0.47 ± 0.05	$0.042^{ab} \pm 0.004$	11.22 ± 0.57	79.75 ± 12.53	1.98 ± 0.96	$909.07^b \pm 251.60$
T_{4t}	$5.97^b \pm 0.31$	$4.79^b \pm 0.46$	0.54 ± 0.14	$0.045^b \pm 0.010$	11.97 ± 0.64	88.50 ± 17.05	3.29 ± 1.32	$894.40^b \pm 190.01$
Ddl	4	4	4	4	4	4	4	4
Probability	0.001	<0.001	0.058	0.036	0.075	0.101	0.155	<0.001
Signification	S	HS	NS	S	NS	NS	NS	HS

Fisher test at 5%: 1) the difference is not significant between the values assigned by the same letter in the same column; 2) each value is the average of 3 repetitions; 3) NS: Not Significant, S: Significant, HS: Highly Significant. Legend: T_0: Plowing of maize + 0 t ha^{-1} of crop residues (control), T_{0t}: Direct sowing of maize/cowpea + 0 t ha^{-1} of crop residues, T_{1t}: Direct sowing of maize/cowpea + 1 t ha^{-1} of crop residues, T_{2t}: Direct sowing of maize/cowpea + 2 t ha^{-1} of crop residues, T_{4t}: Direct sowing maize/cowpea + 4 t ha^{-1} of crop residues.

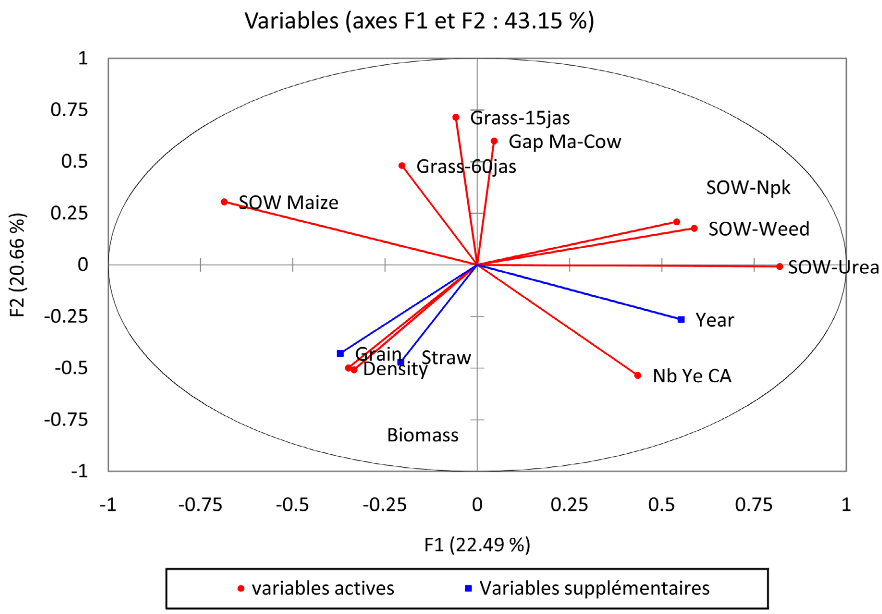


Figure 4. Projection of the variables on a plane constituted by the first two factors (F1 and F2).

the F1 axis discriminated the individuals according to the maize sowing date (SOW maize), the gap between sowing and weeding (Sow-Weed), the difference between sowing and urea supply (Urea) and the year of experimentation (Year) (**Table 6**). Axis F2 was mainly related to the number of years of CA practices in the plot (Nb Yr CA), the gap between maize sowing and cowpea sowing (Sow Ma-Cow) the rate of soil cover by weeds in the plots determined between the 15th and the 20th DAS (Grass-15DAS) and the maize grain and stem yields.

Table 5. Effect of conservation agriculture on soil chemical parameters in 2015.

Depth of soil	Treatment	pH_H_2O	pH_KCl	C (%)	N (%)	C/N	P_total (mg/kg soil)	P_ass. (mg/kg soil)	K_total (mg/kg soil)
0 - 5 cm	T_0	$5.24^{ab} \pm 0.31$	4.66 ± 0.48	0.44 ± 0.11	$0.039^{a} \pm 0.01$	11.08 ± 0.26	$109.27^{b} \pm 5.72$	7.53 ± 4.94	$600.81^{c} \pm 49.71$
	T_{0t}	$5.00^{a} \pm 0.20$	4.43 ± 0.27	0.44 ± 0.08	$0.039^{a} \pm 0.01$	11.11 ± 0.56	$101.59^{a} \pm 8.26$	6.90 ± 1.67	$607.34^{b} \pm 22.91$
	T_{1t}	$5.32^{ab} \pm 0.09$	4.78 ± 0.18	0.52 ± 0.06	$0.047^{b} \pm 0.01$	11.21 ± 0.42	$96.77^{a} \pm 15.84$	6.08 ± 1.20	$527.95^{b} \pm 69.58$
	T_{2t}	$5.37^{b} \pm 0.18$	4.70 ± 0.34	0.50 ± 0.12	$0.045^{b} \pm 0.01$	11.03 ± 0.42	$101.57^{a} \pm 13.62$	6.47 ± 0.54	$488.43^{a} \pm 119.71$
	T_{4t}	$5.39^{b} \pm 0.05$	4.82 ± 0.10	0.55 ± 0.13	$0.047^{b} \pm 0.01$	11.57 ± 0.46	$94.89^{a} \pm 15.98$	6.27 ± 1.95	$442.34^{ab} \pm 63.50$
	Ddl	4	4	4	4	4	4	4	4
	Probability	0.039	0.219	0.258	0.022	0.130	0.026	0.058	0.003
	Signification	S	NS	NS	S	NS	S	NS	S
0 - 20 cm	T_0	5.40 ± 0.32	4.64 ± 0.40	0.48 ± 0.05	0.033 ± 0.01	11.20 ± 0.28	118.81 ± 11.97	8.78 ± 3.29	$666.57^{b} \pm 45.76$
	T_{0t}	4.95 ± 0.24	4.26 ± 0.22	0.39 ± 0.04	0.034 ± 0.01	11.39 ± 0.62	90.13 ± 8.30	5.92 ± 1.16	$534.95^{a} \pm 39.89$
	T_{1t}	5.30 ± 0.17	4.52 ± 0.25	0.42 ± 0.04	0.035 ± 0.01	11.97 ± 0.42	85.28 ± 14.44	4.14 ± 1.17	$514.83^{a} \pm 52.07$
	T_{2t}	5.39 ± 0.05	4.57 ± 0.26	0.35 ± 0.08	0.031 ± 0.01	11.59 ± 1.38	79.56 ± 14.71	4.12 ± 0.57	$429.19^{a} \pm 69.45$
	T_{4t}	5.54 ± 0.02	4.84 ± 0.11	0.42 ± 0.09	0.036 ± 0.01	11.64 ± 0.53	90.05 ± 10.84	6.49 ± 1.53	$481.71^{a} \pm 63.63$
	Ddl	4	4	4	4	4	4	4	4
	Probability	0.071	0.319	0.415	0.088	0.693	0.118	0.091	0.015
	Signification	NS	NS	NS	NS	NS	NS	NS	S

Fisher test at 5%: 1) the difference is not significant between the values assigned by the same letter in the same column; 2) each value is the average of 3 repetitions; 3) NS: Not Significant, S: Significant, HS: Highly Significant. Legend: T_0: Plowing of maize + 0 t ha^{-1} of crop residues (control), T_{0t}: Direct sowing of maize/cowpea + 0 t ha^{-1} of crop residues, T_{1t}: Direct sowing of maize/cowpea + 1 t ha^{-1} of crop residues, T_{2t}: Direct sowing of maize/cowpea + 2 t ha^{-1} of crop residues, T_{4t}: Direct sowing maize/cowpea + 4 t ha^{-1} of crop residues.

Table 6. Squared cosines of variables.

	Axe F1	Axe F2
Biomass	0.112	0.258
Nb Ye CA	0.189	**0.285**
SOW Maize	**0.471**	0.094
Gap Ma-Cow	0.002	**0.361**
Sow-Weed	**0.345**	0.031
Sow-Npk	0.292	0.043
Sow-Urea	**0.671**	0.000
Grass-15 JAS	0.003	**0.512**
Grass-45 JAS	0.042	0.231
Density	0.122	0.249
Grain	0.193	**0.256**
Straw	0.085	**0.436**
Year	**0.480**	0.110

The values in bold correspond for each variable to the factor for which the square cosine is the largest.

The HAC gave 3 classes of CA practices (Table 7). An analysis of the characteristics of these classes showed that class 1 (n = 13) was characterized by a low maize stocking density, high grass cover between the 45th and 55th DAS, and low yields. Class 2 (n = 14) was characterized by late weeding, late urea feeding and a high grass weed rate between the 15th and 20th DAS. Class 3 (n = 3) stood out from Class 1 and Class 2 through a significant supply of straw for soil cover, early urea input, the higher number of years of CA practices in the plot, and higher maize yields.

3.2.2. Effect of CA on Weeds

The results showed that the rate of soil cover by weeds varied between 18% and 59% (Table 8). For Class 1, the weed rate for CA plots was 20.24 and 35.51% for the 15th and 45th DAS, respectively. For the control plots, the weed rate was 33.61 and 19.04%, respectively, on the 15th and 45th DAS. For this class 1, the difference between the control and CA values was significant ($p < 0.05$).

For classes 2 and 3, the difference between the control and CA values was not significant ($p > 0.05$). For Class 2, there was a tendency to have a lower control of weed in CA plots compared to the control plots regardless of the measurement period. For class 3, there was a downward trend in the rate of weed cover on the 15th DAS and a tendency to increase on the 45th DAS in the CA plots compared to the control plots.

3.2.3. Effect of CA on Yields

The maize densities observed were low in the CA plots for all classes (Table 9).

Table 7. Characteristics of conservation agriculture practice classes.

	Class 1	Class 2	Class 3	CV (%)	F	Pr > F	Significant
Nb parcelles	13	14	3				
Biomass	3906^b	3760^b	16,562^a	88.11	39.776	0.000	Yes
Nb Ye CA	2	2	3	37.14	1.543	0.232	No
SOW Maize	176	181	182	5.25	1.394	0.265	No
Gap Ma-Cow	20	21	18	31.60	0.185	0.832	No
Sow-Weed	27^b	40^a	24^b	46.88	3.489	0.045	Yes
Sow-Npk	19	21	16	51.21	0.295	0.747	No
Sow-Urea	49^a	52^a	32^b	25.80	3.825	0.034	Yes
Grass-15 JAS	20.24^b	41.57^a	18.00^b	61.76	7.483	0.003	Yes
Grass-45 JAS	35.51	41.86	58.61	58.33	1.191	0.319	No
Density	29,872	31,210	38,241	30.72	0.919	0.411	No
Grain	1089.40	1180.88	2308.48	67.92	2.940	0.070	No
Straw	1501.83	1530.09	2120.69	58.79	0.559	0.578	No

Fisher test at 5%: the difference is not significant between the values assigned by the same letter in the same line.

Table 8. Effect of conservation agriculture (CA) on weediness rate (%).

	Control	CA	CV (%)	F	Pr > F	Significant
			Class 1 (n = 13)			
Grass-15 JAS	33.61[a]	20.24[b]	58.04	5.636	0.026	Yes
Grass-45 JAS	19.04[b]	35.51[a]	68.08	6.176	0.020	Yes
			Class 2 (n = 14)			
Grass-15 JAS	33.43	41.57	55.07	1.092	0.306	No
Grass-45 JAS	26.07	41.86	68.53	3.521	0.072	No
			Class 3 (n = 3)			
Grass-15 JAS	25.67	18.00	76.28	0.272	0.630	No
Grass-45 JAS	31.28	58.61	67.76	1.275	0.322	No

Fisher test at 5%: the difference is not significant between the values assigned by the same letter in the same line; Grass-15 DAS: grass cover rate of plots 15 - 20 days after sowing, Grass-45 DAS: grass cover rate of plots 45 - 55 days after sowing.

Table 9. Effect of conservation agriculture (CA) on maize yield.

	Control	CA	CV (%)	F	Pr > F	Significant
			Class 1 (n = 13)			
Maize density (plants/ha)	39,017[a]	29,872[b]	30.85	5.724	0.025	Yes
Maize grain yield (kg/ha)	1630.43	1089.40	75.45	1.870	0.184	No
Maize straw yield (kg/ha)	2065.62	1501.83	58.04	2.005	0.170	No
Cowpea grain yield (kg/ha)	-	141.32	30.92	-	-	-
Cowpea hay yield (kg/ha)	-	389.96	80.19	-	-	-
			Class 2 (n = 14)			
Maize density (plants/ha)	41,905[a]	31,210[b]	34.25	6.063	0.021	Yes
Maize grain yield (kg/ha)	1413.95	1180.88	53.19	0.792	0.382	No
Maize straw yield (kg/ha)	1616.93	1530.09	50.46	0.081	0.778	No
Cowpea grain yield (kg/ha)	-	275.69	69.69	-	-	-
Cowpea hay yield (kg/ha)	-	403.68	70.86	-	-	-
			Class 3 (n = 3)			
Maize density (plants/ha)	48,982	38,241	22.34	2.295	0.204	No
Maize grain yield (kg/ha)	2675.12	2308.48	61.10	0.071	0.803	No
Maize straw yield (kg/ha)	2920.97	2120.69	45.99	0.667	0.460	No
Cowpea grain yield (kg/ha)	-	35.42	8.32	-	-	-
Cowpea hay yield (kg/ha)	-	374.58	59.57	-	-	-

Fisher test at 5%: The difference is not significant between the values assigned by the same letter in the same line.

Yields evolved in the same direction as densities. However, except for class 3, the difference between CA and control treatments was significant ($p < 0.05$) for density.

For yields, the values were generally lower in CA plots compared to the control for all classes but the difference between treatments was not significant ($p > 0.05$).

Additional cowpea grain production of 141, 276, and 35 kg ha^{-1} was recorded in the CA plots for classes 1, 2, and 3, respectively. Cowpea fodder production was 390, 404, and 375 kg ha^{-1}. The cowpea grain yield measurements were carried out in 4 plots for classes 1 and 2, and in 2 plots for class 3. The cowpea yields were mean values obtained from 11, 12 and 3 plots for classes 1, 2, and 3, respectively.

4. Discussion

4.1. Effective Improvement of Soil Fertility Parameters under Higher Crop Residue Mulching

Our on-station experiments showed significant differences between treatments for chemical parameters in the 0 - 5 cm soil horizon. In this soil horizon, soil nitrogen levels ranged from 0.03% to 0.05% and were significantly higher in the CA treatments. There was also an improvement in the pH value of the CA treatments compared to the conventional treatment. This increase could be related to the organic matter content of the soil that was observed in the CA treatments, but with no significant difference at the 5% threshold. Dounias [36] noted that an increase in soil organic matter decreased the acidity of the soil. Total phosphorus and total potassium content also showed statistically different results. The phosphorus and potassium contents were higher at a depth of 0 - 5 cm than at 0 - 20 cm. The work of [37] showed, in CA cropping systems, that phosphorus and potassium accumulate in the surface horizon and decrease at depth, while they are distributed homogeneously over the plowed soil layer.

For the 0 - 20 soil horizon, the analysis of variance of the chemical data did not detect any significant differences between treatments. Consequently, the improvement in soil chemical properties under CA in this horizon would appear to occur gradually. Indeed, [38] showed an increase in soil carbon content from 23% to 29% after 5 years of continuous CA cultivation. According to [39], the beneficial effects of CA on soil chemical parameters are observed after a few years of continuous implementation.

The data showed a general trend of a soil macrofauna density increase under the CA treatments compared to the conventional treatment. However, the differences between treatments were not significant at the 5% threshold, except for the termite population 45 DAS (2014), which was significantly higher in treatment T_{4t}. This macrofauna density increase could be explained by the presence of crop residues, which are a source of carbon essential for the feeding of macrofauna [40] [41]. According to [42], the quality and abundance of organic matter are the factors controlling soil macrofauna. The high proportion of termites in the macrofauna population can be explained by their powerful grinding mouthparts and because they play a leading role in the degradation of crop residues. Furthermore, [43] showed that in areas where rainfall was under 1000 mm, termites dominated the macrofauna population of the soil. The soil moisture conditions could also explain the density of termites. Indeed, a high density of termites was obtained after the dry spell recorded during the 2014 cropping season, which occurred just before the determination of the macrofauna at 45 DAS. Between the 45th and 90th DAS of both cropping seasons, a drop in the macrofauna population was observed, which may have been due not only to a decrease in the amount of residue but also to an increase in humidity. Conversely, earthworms and millipedes did not show significantly different results between treatments with respect to their density. The physiology of these two species may explain the absence of a mulch effect on their density.

The results for soil respiratory activity showed an overall release (difference not significant at the 5% threshold) of carbon dioxide (CO_2) for the CA treatments compared to the conventional treatment. Soil coverage stimulates the macrofauna of the soil and its activity affects that of the microorganisms responsible for mineralization [44]. Our results contradict those obtained by [41] which showed that the use of compost or the combination of straws with urea leads to a more intense release of CO_2 with respect to the exclusive use of urea. However, the organic carbon content of the different treatment soils was virtually the same in the 0 - 20 cm horizon from which the samples were taken to measure respiratory activity.

Broadly, the CA treatment with 4 tons of straw appeared to be the one that can help improve soil fertility parameters compared to the other treatments, the lower rate of crop residue mulching not showing significant differences with the control treatment.

4.2. Crop Residues Mulching, One of the Farmers' Challenge When Implementing CA Cropping Systems

The on-farm experiments showed on-farm diversity for the components of the crop management sequences. The number of years of CA practices in the plot, the amount of straw for soil cover, maize density, weeding and urea application period were sources of diversity in CA practices that were associated to contrasted weed rates and yields.

The correlation between these components of the crop management on weeds and yields has been acknowledged by authors in other contexts. The specific correlation between the delay in urea application and CA crop yields can be explained by the fact that under CA, nitrogen is readily immobilized by microorganisms causing a lack of nitrogen for crops [45]. Early urea application would therefore reduce nitrogen stress and promote good crop production. The correlation between the number of years of CA practices and yields have also been showed by [46].

In two of the three classes, the rate of weed was low in the CA plots compared to the control plots during the crop emergence and growth phases (15-20 DAS). However, between the 45th and 55th DAS, the weed rate tended to be greater in the CA plots of the three classes compared to the control plots. This can be explained by the fact that the amount of residues was insufficient to cover the entire soil area and prevent weed development [19] [47]. It can be specifically explained by the structure of the residues, which was coarse and did not allow good soil coverage. The strategy of the farmers during the experiments was to use a diversity of residues. With the constraint of crop residue availability, tree branches and shrubs were mainly used as ground cover. As weeding was primarily manual (grubbing), it was difficult to effectively eliminate weeds between branches, which would have facilitated their abundance between the 45th and 55th DAS in the CA plots.

The CA treatments resulted in a non-significant decrease in maize grain and straw yields compared to the control treatments in all classes. However, the difference between control and CA was lower for the class 3 characterized by a better management of the crop. Such management practices could account for this decline. To this should be added weed pressure, poor development of the root system, and the competition for water and nutrients between the associated crops in the CA plots.

Nevertheless, these mixed results for the main crop need to be qualified in the light of the additional biomass produced by cowpea, which was capable of compensating for the loss observed in the main crop. The introduction of cowpea into the cropping system, in addition to its potentially positive medium-term effect on soil properties [48], also allows diversification of the diet in a cash crop-oriented zone. Moreover, the additional haulms obtained make it possible to enrich the nutritional value of the animal ration [49] [50].

4.3. Is CA a Solution in the West African Sudanian Conditions?

[51] showed the need in sub-Saharan Africa to identify niches where conservation agriculture can be implemented rather than promoting broad-scale dissemination. Our study combines on-station and on-farm experiments to give a broad perspective of the performances of CA cropping systems. Our study contributes to the definition of such niches by making it possible to give an order of magnitude for the quantity of straw needed for soil cover taking into account farmers' distinct capacities of management of the crop sequence and to show that it is a decisive parameter for ensuring the good functionality of the CA system.

Broadly, the CA treatment with 4 tons of straw appeared to be the one that can help improve soil fertility parameters compared to the other treatments if the challenge is to achieve positive results within a reasonable timeframe for the farmer. Nevertheless, the on-farm experiments confirmed the difficulty for farmers to collect enough biomass for soil cover since farmers of classes 1 and 2 collected an average biomass lower to this threshold of 4 tons.

Procuring at least 4 tons per ha of crop residues is challenging and involves increased monitoring of fields. Such monitoring is only possible in fields near the homesteads, unless the rules for access to land between farmers and herders are redesigned. It can be assumed that the CA treatment with 2 tons of straw could, in the longer term, have significant results for the fertility parameters measured. This raises the problem of testing CA on farms where farmers are not necessarily ready to continue experiments over a long duration without concrete evidence of the superiority of the treatments for yields.

This long timeframe before observing positive results for soil fertility combined with the low availability of crop residues and with the complexity for farmers to manage the different components of the crop management sequence is likely to explain the reasons for its low adoption in West African CA cropping systems [22] and the increasing doubts about ecological intensification based on the principles of CA [52]. In this research, prior training of farmers was required to explain the complexity of the biophysical processes at play behind the principles of CA. And paradoxically, despite the negative returns obtained, the farmers' perception of the research remained positive [53]. Furthermore, [53] showed that involving a diversity of farmers (livestock and non-livestock farmers) in participatory research on CA could lead to agreements on the rules of access to crop residues. The study of [54], recommends training and extension support for CA adoption as well as more access to credit opportunities for increased households' adoption of CA.

In the context of western Burkina Faso, where mixed crop-livestock systems are dominant, CA is possible for farmers interested in improving soil fertility parameters and having the technical and logistical capacities to collect more than 4 tons ha^{-1} of biomass and to manage the different components of the crop sequence. Conservation agriculture cannot be the unique promoted solution to improve soil fertility. It may be supported by broader organizational changes to provide advisory support to farmers and to renew rules of access to crop residues and land.

5. Conclusion

This study was conducted on-station and on-farm in order to determine the effects of distinct amounts of mulching on CA cropping system performances with a deeper assessment on-station (soil fertility parameters), whereas on-farm we mainly assessed the feasibility of farmers collecting crop residues and the associated effects on weeds and yields. The effect of soil cover on biological parameters seemed to be greater on termites and less so on earthworms and millipedes. Soil biological activity was positively correlated with organic matter content but no significant differences were observed. Concomitantly, this organic matter led to a reduction in soil acidity. For the chemical parameters, the greatest effects of mulching were the reduction in soil acidity and the increase in total nitrogen and total potassium. Other chemical parameters were also improved under CA but in smaller proportions. Treatment T_{4t} (4 t ha^{-1} of straw) was the best option for improving soil fertility. However, we found three classes of on-farm management according to the component of the crop management sequences which confirmed that such an amount of soil cover was difficult for farmers to achieve, as were the other components of the crop management sequences. Promotion of CA must be targeted to farmers.

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Conflicts of Interest

The authors declare no conflict of interest.

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