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Effects of four years of continuous conservation agriculture practice on soil fertility and maize (*Zea mays* L.) yield in agroecological transition context in western Burkina Faso

Kalifa Coulibaly, Alain PK Gomgnimbou, Idriss Sermé, Joseph FK Sanon and Hassan B Nacro

Kalifa Coulibaly
Laboratoire d'étude et de recherche sur la fertilité du sol (LERF), Institut du Développement Rural (IDR), Université Nazi BONI (UNB); BP 1091, Bobo-Dioulasso, Burkina Faso

Alain PK Gomgnimbou
Institut de l'Environnement et de Recherche Agricole (INERA), Station de Farako-Bâ, 01 BP 910 Bobo 01, Burkina Faso

Idriss Sermé
Institut de l'Environnement et de Recherche Agricole (INERA), Station de Kamboinsé, BP 476 Ouagadougou 01, Burkina Faso

Joseph FK Sanon
Laboratoire d'étude et de recherche sur la fertilité du sol (LERF), Institut du Développement Rural (IDR), Université Nazi BONI (UNB); BP 1091, Bobo-Dioulasso, Burkina Faso

Hassan B Nacro
Laboratoire d'étude et de recherche sur la fertilité du sol (LERF), Institut du Développement Rural (IDR), Université Nazi BONI (UNB); BP 1091, Bobo-Dioulasso, Burkina Faso

Corresponding Author:
Kalifa Coulibaly
Laboratoire d'étude et de recherche sur la fertilité du sol (LERF), Institut du Développement Rural (IDR), Université Nazi BONI (UNB), BP 1091, Bobo-Dioulasso, Burkina Faso

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Abstract

The objective of this study is to show the potential of conservation agriculture on chemical parameters, soil respiration activity and maize yields after 4 years of continuous CA practices. The experimental design is a factorial block with two treatments and three replications. The conventional system (CS = plowing + maize) is compared to the conservation agriculture system (CA = 2 t/ha of straw + direct seeding of maize/ cowpea). The results show that the CA system significantly increased soil pH (11.32%), carbon (81.13%), nitrogen (85.71%) and potassium (97.55%) in the 0-5 cm soil layer compared to the conventional system. The AC system improves the soil respiration activity. It induced a non-significant increase in grain (10.89%) and straw (16.01%) yields of maize compared to SC. Total forage biomass production (straw with or without stover) showed a significant increase of 39.06% in CA compared to SC. It can be concluded that CA with 2 t/ha of straw as cover can ensure sustainable management of tropical soils and improve productivity of cropping systems. However, the beneficial effect would only be noticeable after a few years of continuous CA practice (4 years for our study).

Keywords: Mulching, direct sowing, chemical fertility, yield, Burkina Faso

Introduction

The agricultural sector plays a major role in the socio-economic development of Sub-Saharan African countries. This sector is the main source of income for populations and contributes significantly to the national wealth of these countries. In Burkina Faso, agriculture contributes about 25% of the Gross Domestic Product (DGPER, 2010) [5] and employs over 80% of the population. Despite this socio-economic importance, the agricultural sector is facing several problems, including climate change and population growth. Indeed, the strong demographic growth (annual increase of 3.1% according to INERA, 2014) [12] in the context of an extensive and not very productive agriculture, has led to an increasing pressure on natural resources. This pressure is reflected in the expansion of cultivated areas, which is taking place even on land that is less and less suitable for crops (Zoundi *et al*. 2006) [25]. The result is the elimination of long fallow periods which was the natural basis for the restoration of organic matter and soil fertility (Gura *et al*., 2022; Masse, 2007; Sédogo, 2008) [11, 15, 20]. This extensive agriculture with very low inputs and no recycling of crop residues leads to negative nutrient balances and does not allow for long-term maintenance of soil fertility (Bado, 2002; Kutamahufa *et al*., 2022) [2, 14].

In order to overcome this constraint, new production systems such as conservation agriculture are being tested to ensure the sustainability of production. Conservation agriculture is based on three fundamental principles, namely minimum tillage, soil protection through mulch cover and crop diversification. According to the FAO (2005) [10], it is an interesting alternative to meet the multiple challenges facing the agricultural sector today, particularly in developing countries such as Burkina Faso. However, it should be noted that the application of this cropping system is done in an adaptive manner according to the agro-ecological environment. The problem is to adapt conservation agriculture to different types of production systems in order to fight against food insecurity and rehabilitate soils. In order to address this issue, studies have been conducted since 2013 by the ABACO (Agro-ecology Based Aggradation Conservation agriculture) project in the village of Koumbia. The present study shows the back effects after four (04) years of continuous practice of CA on chemical parameters, soil respiration activity and maize yields.

Material and methods

Study site

The study was carried out in the village of Koumbia (11° 14' 11" North; 3° 41' 47" West), located 67 km northeast of Bobo-Dioulasso in the rural commune of Koumbia (Figure 1). The commune of Koumbia is characterized by a Sudanian climate. In general, the amount of water collected over the past 10 years has ranged from 775 mm to 1,202 mm with an average of 966.24 mm of water per year. The soils found in the area are mostly of the leached and slightly leached tropical ferruginous type (30% of the provincial territory), rich in iron dioxide, rusty in color and of average agronomic value.

Experimental design

The experimental design was a factorial block, consisting of two treatments and three replications within each plot. It was integrated into another set-up previously set up since 2013 in the framework of the ABACO project (Agro-ecology Based Aggradation-Conservation agriculture). It consisted of two plots where on the one hand we had the practice of conservation agriculture and on the other the practice of the conventional system. The treatments compared were (i) the conventional system (CS): plowing + 0 t/ha of straw + maize and (ii) the conservation agriculture system (CA): 2 t/ha of straw + direct seeding of maize/ cowpea (in association).

On each treatment in the conservation agriculture system, straw was applied before sowing. The treatments consisted in elementary plots of 10 m x 05 m (50 m2).

Conduct of the experiment

A herbicide treatment with glyphosate 360 g/L was carried out before sowing on the AC plots and 2 t/ha of straw were also brought in. A ploughing was done before sowing for the SC treatments. When planting maize (*Zea mays* L.) of the SR21 variety with an intermediate cycle (97 days), the spacing was 40 cm between bunches and 80 cm between lines. Cowpea (*Vigna unguiculata* L. Walp) of the variety KVX745 11p (70 days of cycle) was planted 21 days after maize, at the same spacing and between the maize lines on each AC plot. A dose of 150 kg.ha-1 of NPK compound fertilizer (15-15-15) was applied on the 15th day after sowing (DAS) of maize for all treatments. Then a dose of 50 kg.ha-1 of urea at 46% N was applied in two fractions at 30 and 45 days after sowing. Weeding was carried out on the SC treatments by hand with a daba at 35th and 90th days of the month. The first treatment of cowpea with K-Optimal was carried out at 35 days of cowpea corresponding to the stage of flower buds emission and the second at 50 days of cowpea corresponding to the stage of pod formation.

Monitored parameters

Determination of chemical parameters

The pH water and pH KCl are measured with an electronic pH meter in a suspension of the sample in distilled water and in a solution of KCl at a ratio of 1/2.5 (AFNOR, 1981). Total organic carbon was determined using the Walkley-Black method (1934). Carbon is oxidized by an excess of potassium dichromate in concentrated sulfuric acid. The excess dichromate is determined by Mohr's salt. Total nitrogen and total phosphorus were determined by automatic calorimetry after mineralization of soil samples by the KJELDAHL method. Total potassium was determined by flame photometry after mineralization. Assimilable phosphorus was extracted by the Bray I method (Bray and Kurtz, 1945) [3].

Determination of soil respiration activity

Analyses of soil respiratory activity were performed by the method of CO_2 trapping in soda (Dommergues, 1960) [7]. The soil samples were taken from the 0-10 and 10-20 cm horizons. They consisted in taking for each treatment, a sample of one hundred (100) grams of soil, sieved to 2 mm, and to moisten them to 2/3 of the maximum retention capacity. This soil was then introduced into a hermetically sealed jar; two bottles, one containing soda (NaOH 0.1 N) to trap the CO_2 released and the other containing distilled water to maintain constant humidity, were placed in each jar (Photo 2). The whole set is placed in a chamber set at 30 °C for 21 days. The amount of CO_2 released is measured daily during the first 7 days of incubation, then every other day until day 21. The CO_2 released during the study is trapped by soda (NaOH,0.1 N) and precipitated as sodium carbonate by 3% barium chloride. The excess soda (NaOH) is neutralized by hydrochloric acid (HCl 0.1 N) in the presence of phenolphthalein. The amount of CO_2 released per day is expressed in mg/100 g dry soil and given by the following formula (Dommergues, 1960; Tiessen and Moir, 1993) [7, 22]:

$$Q\ (\text{mg}) = [V\ \text{HCl}\ (\text{blank}) - V\ \text{HCl}\ (\text{treatment})] \times 2.2$$

Where:

V HCl (blank) = volume of hydrochloric acid for the control

V HCl (treatment) = volume of hydrochloric acid for the treatment

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

Determination of crop yields

Yields are determined on the 7 central lines of each elementary plot over a length of 3 m per line, which corresponds to an area of 3 m x 5.6 m or 16.8 m2.

The corn cobs obtained are dried and shelled manually by treatment and by repetition. The obtained grains are weighed with an electronic scale. The corn stalks are cut at the level of the collar and dried in an oven at 75 °C for 72 hours. They are weighed with an electronic scale after drying to obtain the dry weight in grams (g). The determination of cowpea seed yield and hay yield was done following the method used to determine grain and straw yield of maize.

Statistical analysis

The collected data were entered using Microsoft office Excel 2013 software. These data were subjected to an analysis of variance (ANOVA) with the XLSTAT software

Version 2015.4.01.22368. Means were separated at the 5% threshold using Fisher's test.

Results

Effects of conservation agriculture on chemical parameters

The effect of conservation agriculture on soil chemical properties is recorded in Table 1. These results show an improvement in soil chemical characteristics under conservation agriculture compared to the conventional system. On the 0-5 cm soil layer, there was a significant increase ($p<0.05$) in pH water (8.47%), pH KCl (11.32%), total carbon (81.13%), total nitrogen (85.71%), total potassium (97.55%) and available potassium (125.42%). At the level of total and available phosphorus, although the highest values were recorded in conservation agriculture, there was no significant difference between the two treatments ($p<0.05$).

At the 5-10 cm soil depth, the analysis of variance shows that the conservation agriculture system only significantly increased ($p<0.05$) pH (pH water and pH KCl) and potassium (total and available). As for the other chemical parameters, notably total carbon, total nitrogen, total phosphorus and available phosphorus, the difference was not significant ($p<0.05$) between the two treatments. Nevertheless, the highest values are always those recorded on the AC plot.

Effects of conservation agriculture on soil respiration activity

Figure 2 shows the daily CO_2 release at 62 DAS for the 0-10 cm and 10-20 cm layers under conservation agriculture compared to the conventional system. These results show that CO_2 release varies with soil depth. Overall, the amount of CO_2 released on the Conservation Agriculture plot was much higher than on the conventional plot, regardless of soil depth. Overall, there was a decrease in CO_2 release for all treatments during the 21-day incubation period. The highest CO_2 release for the 0-10 cm layer is recorded in conservation agriculture (248.6 mg/kg soil) while the lowest release is obtained in conventional system (15.1 mg/kg soil). For the 10-20 cm layer, the same observation is made with a release of 148.1 mg/kg of soil for conservation agriculture against 1.1 mg/kg of soil obtained in the conventional system. Figure 3 shows the cumulative CO_2 release for the conservation agriculture system and the conventional system. The amount of CO_2 released under Conservation Agriculture is much higher than under the conventional system.

Effects of Conservation Agriculture on Corn Yields

Figure 4 shows the grain and straw yields of corn for the different treatments. The lowest corn yields are obtained on the conventional system treatments. The results show that the highest corn grain yield was observed in the AC treatment with 2888.89 kg/ha compared to 2605.16 kg/ha in the SC treatment. In terms of straw yield, the AC treatment had the highest yield (2773.81 kg/ha), and SC the lowest (2390.87 kg/ha). The analysis of variance showed no significant difference at the 5% level between treatments for all yields.

Figure 5 compares the total forage biomass production (straw with or without chaff) between the conventional and the conservation agriculture system. It is noted that the conservation agriculture treatment has the highest yield (3324.69 kg/ha in CA) compared to the conventional system (2390.87 kg/ha in SC). The analysis of variance showed a significant difference at the 5% level.

Discussion

Analyses on chemical parameters reveal that conservation agriculture would significantly improve soil chemical properties. These results are in line with those reported by Scopel *et al.* (2005) [19] who obtained an increase in soil carbon content from 23 to 29% after 5 years of experimentation under a cover crop system. The increase in carbon content under conservation agriculture is much more noticeable in the 0-5 cm soil layer. Scopel *et al*, (2005) [19] also obtained a significant increase in carbon content in the 0-2.5 cm and 2.5-5 cm depths after five years of practice of a conservation agriculture system in the semi-arid zone of western Mexico. This can be explained by the fact that there is an accumulation of organic matter on the soil surface. Dounias (2001) [9] finds that in the tropics, cover cropping systems improve organic matter levels in soil depths less than 10 cm.

The conservation agriculture system significantly increased soil pH, nitrogen and potassium levels. This can be attributed to the accumulation of organic matter on the soil surface, but also to the insertion of legumes into the cropping system during the four years of continuous practice. Indeed, showed that the zaï technique in combination with compost raises the pH level. Sidibé (2013) [21] and Wendlandt *et al.* (2022) [24] find that legumes improve soil nitrogen content. Conservation agriculture did not induce a significant difference on soil phosphorus, although the highest value was noted at this level. This result contrasts with Doumbia (2016) [8] who found after three years of conservation agriculture, higher total and available phosphorus values in the conventional system. This would mean that phosphorus would require a longer cropping period under conservation agriculture for a significant difference to be observed with the conventional system.

Soil respiratory activity is manifested by the release of carbon dioxide (CO_2), which in fact reflects the degradation processes of organic matter (Nacro, 1997) [16]. It must be said that the respiratory intensity of a soil will depend on the activity of microorganisms and the amount of organic matter found in it. Our results show that the highest release of CO_2 is observed in conservation agriculture. The important release of CO_2 indicates that the microbiological activity is more intense than in the conventional system. Indeed, the organic matter stimulates the biological activity of the soil. These results are similar to those of Doamba *et al*., (2011) [6] who show that the use of stone cordons promotes a significant release of CO_2 due to the accumulation of organic matter on the soil surface. They find that soil respiratory activity is higher the more dense the macrofauna in the soil. Soil macrofauna not only participate in the mineralization of organic nitrogen through their digestion, but also constitute an often large and mobilizable reserve by themselves when they die (Mathieu, 2004) [26]. Kohio (2015) [13] and Doumbia (2016) [8] have also observed higher CO_2 emissions in conservation agriculture systems compared to conventional systems.

Our results in terms of grain yield did not show a significant difference between the two systems, but there was a trend towards an increase in the treatments under the conservation agriculture system. Scopel *et al*. (2005) [19] found that after five years of continuous practice of conservation agriculture, grain yields of corn increased by 170-190% compared to the conventional system. Several authors (Naudin *et al*., 2010; Schaller, 2013) [27, 18] agree that the effects of conservation agriculture on crop yields are not noticeable in the first years of adoption. It takes several years of implementation (+5 years) for the system to reach ecological equilibrium in order to have the favorable impacts on yields. However, Naudin *et al*. (2005) [17] observed slightly higher cotton yields after three years under the conservation agriculture system than under the conventional system in northern Cameroon. This means that the number of years of cultivation is not the only determinant (Kohio, 2015) [13]. He adds that climatic conditions could also be a second determinant underlying the divergence in results. In the climatic context of western Burkina Faso, Doumbia (2016) [8] found after three years under the conservation agriculture system, lower yields compared to the conventional system. In the present study, where the experiment is in its fourth year of testing, an improvement in yield under conservation agriculture is beginning to be noted. This is reflected in the fact that the physico-chemical and biological parameters of the soil have improved.

Total forage biomass production (straw and chaff) was better with the CA treatments compared to the conventional treatments. These results corroborate those obtained by Coulibaly *et al*. (2012) [4] who showed that cereal-legume associations allow for an increase in forage biomass (straw and tassel combined) compared to pure cropping. Indeed, they recorded increases of 22-29% in forage biomass for maize-legume associations compared to maize monoculture.

Table 1: Variation of some soil chemical characteristics according to the treatments

Depth		**pH water**	**pHKCl**	**Carbon (%)**	**N (%)**	**C/N**	**Total P (mg/kg)**	**Available P (mg/kg)**	**Total K (mg/kg)**	**Exchangeable K; (mg/kg)**
0-5 cm	CS	$5,9^{b}$ (0,03)	$5,3^{b}$ (0,07)	$1,06^{b}$ (0,33)	$0,07^{b}$ (0,02)	14 (1,04)	132,95 (32,54)	13,08 (3,62)	$752,25^{b}$ (195,60)	$62,75^{b}$ (11,56)
	CA	$6,4^{a}$ (0,10)	$5,9^{a}$ (0,22)	$1,92^{a}$ (0,39)	$0,13^{a}$ (0,02)	14 (0,88)	165,20 (8,57)	15,16 (4,22)	$1486,05^{a}$ (217,42)	$141,45^{a}$ (9,75)
	Pr > F	0,002	0,009	0,044	0,022	0,6	0,172	0,552	0,012	0,001
	Significant	S	S	S	S	NS	NS	NS	S	HS
5-10 cm	SC	$5,8^{b}$ (0,03)	$5,1^{b}$ (0,11)	0,87 (0,21)	0,06 (0,01)	15 (1,25)	111,47 (21,70)	12,27 (4,30)	$662,47^{b}$ (162,37)	$44,55^{b}$ (15,62)
	CA	$6,2^{a}$ (0,19)	$5,6^{a}$ (0,21)	1,04 (0,10)	0,07 (0,01)	15 (0,48)	127,52 (23,26)	9,80 (2,42)	$1160,15^{a}$ (180,60)	$92,98^{a}$ (16,34)
	Pr > F	0,013	0,015	0,265	0,326	0,589	0,432	0,435	0,024	0,021
	Significant	S	S	NS	NS	NS	NS	NS	S	S

Fisher test at the 5% level:
The difference is significant between values assigned by different letters in the same column;
Each value is the mean of 3 replicates; values in parenthes represent the standard deviations
HS: Highly Significant; NS: Not Significant; S: Significant. CA: conservation agriculture; CS: conventional system
Fisher test at the 5% level:

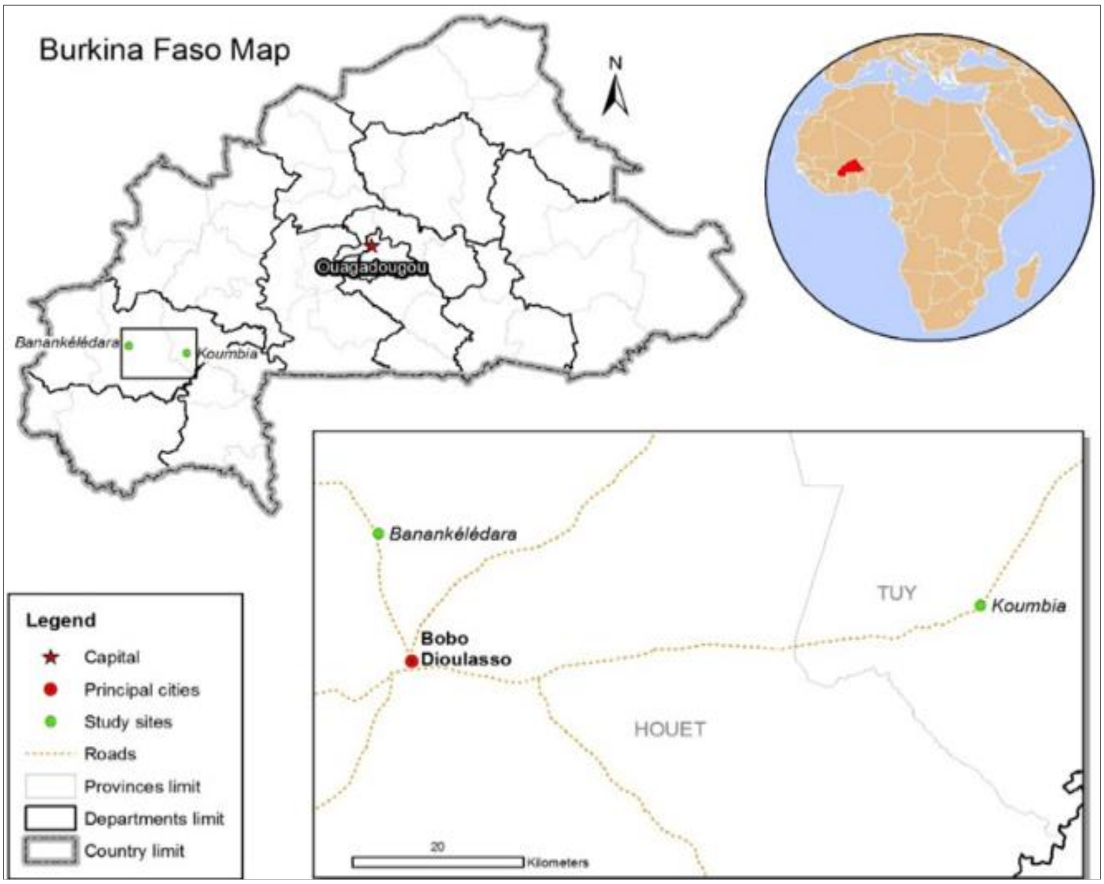
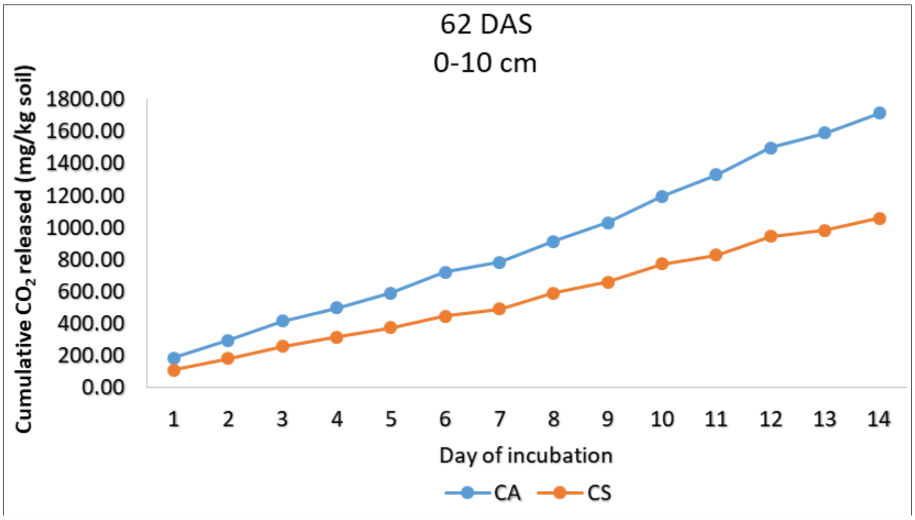


Fig 1: Geographical location of Koumbia

Fig 2: Daily change of CO_2 released according to the treatments, according to different soil layers (each point is the average of 3 replicates)



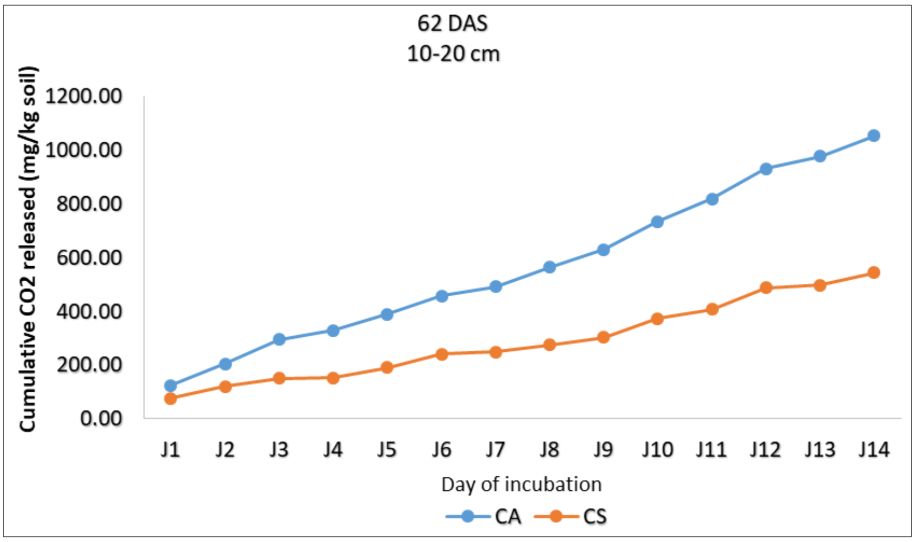


Fig 3: Evolution of the cumulative CO_2 released according to the treatments and the soil layers (each point is the average of 3 replicates). Legend: CA: Conservation Agriculture; CS: conventional system

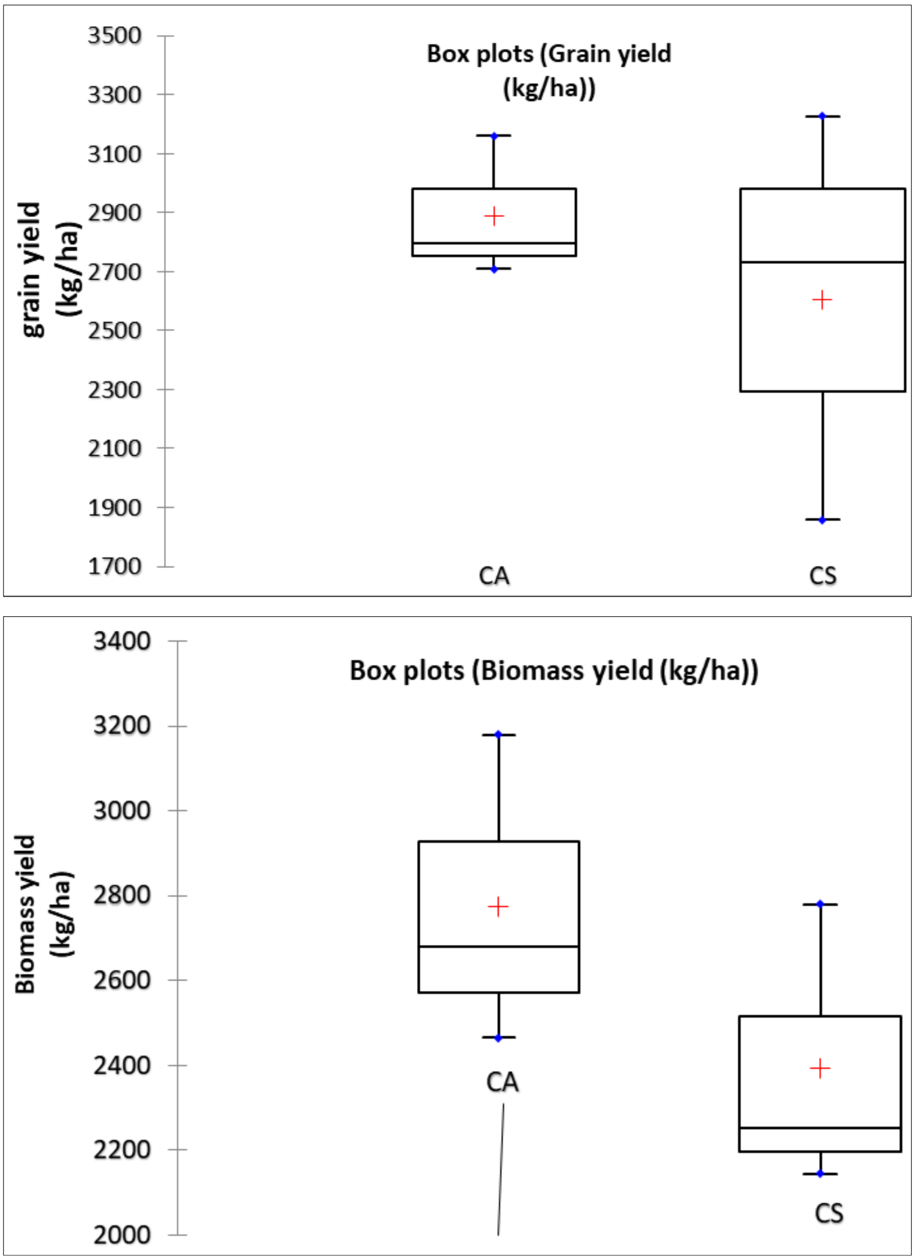
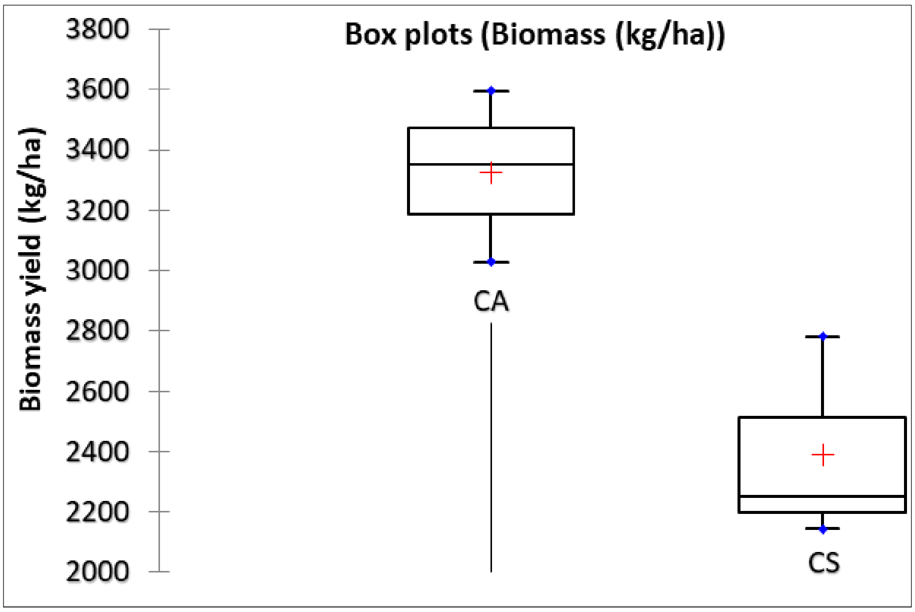


Fig 4: Maize yield as affected by treatments



The red crosses are the means.
The central horizontal bars are the medians.
The lower and upper limits of the boxes are the first and third quartiles, respectively.
The blue points are the minimum and maximum for each yield.
Legend: AC: conservation agriculture; CS: Conventional system

Fig 5: Variation in biomass production (with or without stover) according to the treatments

Conclusion

It can be noted that the CA system improves chemical parameters in the surface layer (0-5 cm) of the soil and respiratory activity compared to the conventional system. In the current context of Burkina Faso, marked by climatic deterioration and declining soil fertility, conservation agriculture can be an alternative for sustainable soil fertility management, by stimulating biological activity and improving the chemical characteristics of the soil. As an agronomic consequence of this study, it can be said that the conservation agriculture system with 2 t/ha of straw is a cropping system that would allow for sustainable management of tropical soils and improved productivity of production systems. Nevertheless, the success of this system in our context requires continuous practice over several years, sufficient biomass production to reduce competition between soil cover and animal feed, and good weed management.

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