INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 25, No. 6, p. 167-179, 2024

RESEARCH PAPER OPEN ACCESS

Effects of tillage and organo-mineral fertilization on soil physicochemical parameters and yields of sorghum [*Sorghum bicolor* (L. Moench)] in western Burkina Faso

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Key words: Tillage, Fertilization, Parameters, Yield, Sorghum, Burkina Faso

http://dx.doi.org/10.12692/ijb/25.6.167-179 Article published on December 05, 2024

Abstract

Sorghum cultivation is limited by poor soils, biotic constraints and unsuitable agricultural practices. This study, which deals with the effects of tillage and fertilization on sorghum production, aims at contributing to the sustainable improvement of the productivity of this sorghum. The experiment was conducted at the INERA research station in Farako-Bâ, following a split-plot set up with four repetitions. The main factor was tillage with three levels, namely mechanized ploughing, mechanized subsoiling and manual scarification and the secondary factor fertilization with three treatments which are T0: no fertilizer; T1: 5 t/ha of compost; T2: 5 t/ha of compost + 100 kg/ha of NPK + 50 kg/ha of urea. The results showed a favourable effect of mechanized subsoiling and mechanized ploughing on grain (1477.64 kg/ha and 1497.49 kg/ha) and straw (44530.69 kg/ha and 450.60 kg/ha) yields compared to manual scarification. However, the tillage did not significantly improve the physico-chemical parameters of the soil apart from the moisture content and the assimilable phosphorus. Organo-mineral fertilization (T2) resulted in substantial gains in grain yield of 379.46 kg/ha compared to organic fertilization alone (T1) and 672.28 kg/ha compared to the control without fertilizer (T0). It also recorded the best straw yield (5101.60 kg/ha). The different interactions between tillage and fertilization did not show significant differences. For the improvement of sorghum productivity in Burkina Faso, ploughing and subsoiling associated with organo-mineral fertilization appear to be the best practices. However, their positive effects on the physicochemical parameters of the soil remain unsatisfactory.

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Introduction

In Burkina Faso, sorghum was the second most cultivated cereal in 2020 and 2021 (FAO, 2022). Several factors, both abiotic and biotic, can explain this drop in production, resulting in a continuous drop in yields. Among the abiotic factors are low soil fertility and increasingly unfavourable rainfall conditions (Ouédraogo, 2014). Several studies have revealed that 70% of soils under cultivation in Burkina Faso have a total nitrogen content of less than 0.06%, nearly 93% have a total phosphorus content of less than 0.06% and 60% have an organic matter content of less than 1% with a low assimilable phosphorus content. In addition to this, inadequate use of agricultural equipment, limited water availability, lack of technical knowledge of farmers, inappropriate tillage measures can modify soil properties by making it vulnerable and thus leading to land degradation that contributes to the maintenance of low agricultural yields compared to potential yields (Constable and Bange, 2015 ; Doni *et al.*, 2017). Also, the elementary principles of soil fertility, which are based on knowledge of the physical and chemical properties of the soil and how these properties act on plant growth (Jones, 2012), are very often misunderstood. In order to enable producers to cope with difficult pedoclimatic conditions and to improve crop productivity, several methods of soil fertility management have been developed by environmental and agricultural research actors. Water and Soil Conservation (WSC) techniques, Soil Defense and Restoration (SRD) techniques, tillage methods and organo-mineral fertilization are among the management methods.

In addition, the determination of optimal fertilization rates for crops (IFDC, 2018) and fertilization methods such as localized fertilizer application or micro-dose with a view to increasing crop yields have been developed. However, it is clear that crop productivity is still facing declining soil fertility and climatic disturbances. It is in this perspective that this latter is inscribed. The general objective of this study was to contribute to the improvement of sorghum production through certain agricultural practices.

Methodology

The study was conducted at the INERA research station in Farako-Bâ. It is located on the Bobo-Banfora axis, about ten kilometers from Bobo-Dioulasso. The geographical coordinates of the station are: 11°06 north latitude, 4°20 west longitude and 405 meters above sea level. The Farako-Bâ research station is located in the South Sudanian zone (Guinko and Fontes, 1995). The amount of water that has fallen at the Faroko-Bâ research station over the last ten years (2014 to 2023) is an average of 1,101.14 mm in 63 rainy days. The most frequently encountered woody species are: *Daniellia oliveri* (Rolfe) Hutch. & Dalz., *Afzelia africana* Smith ex Pers., *Isoberlinia doka*, *Pterocarpus erinaceus* Poir., *Prosopis africana* Taub., *Parkia biglobosa* R. BC. Ex G. Don., *Burkea africana* Hook. F. and *Albizzia chevalieri* Harms (Fontes and Guinko, 1995). Like the soils of western Burkina Faso, those of Farako-Bâ are mainly part of the class of tropical ferruginous soils that are not leached much (Zerbo *et al.,* 1995).

Materials

For the present study, the seed of sorghum of the "kapèlga" variety was used (INERA/CIRAD, 2001). The mineral fertilizers used are: NPK (14-23-14-6S-1B) at 100 kg/ha and pearl urea (46% N) at 50 kg/ha.

Methods

The trial was set up according to a split-plot system with "tillage" as the main factor and "fertilization" as a secondary factor. It was composed of nine (9) treatments with four (4) repetitions for a total of thirty-six (36) elementary plots of 35 m2 (7 m x 5 m) each, separated from each other by a 1 m alley, a 1 m alley surrounding the entire device. Table 1 presents the different treatments and the description of these treatments.

Conduct of the test

Sowing took place in June 2024. The seeding lines were materialized using the radiator and had spacings between the seeding lines of 80 cm and 40 cm between the pockets. Maintenance operations mainly consisted of hoeing, application of mineral fertilizers

(NPK and urea), phytosanitary treatments and ridging.

Data collection

Weight of 1000 grains (WTG)

1000 grains from the harvest of the useful plot were counted and weighed (CIRAD and GRET, 2006).

Grain yield (GY)

This consisted of an assessment of the quantity of grain harvested per unit area. These were the weighing after drying of the grains harvested in the useful plots and the extrapolation to the hectare.

RY $(kg.ha^{-1}) = \frac{P\,(kg) * 10\,000\,m2}{Usable\ area\,(m2)}$; *where P= grain weight*

Straw yield (SY): this is the evaluation of the quantity of above-ground biomass per unit area.

SY $(kg.ha^{-1}) = \frac{P\,(kg) * 10\,000\,m2 * H\,(\%)}{Usable\ area\,(m2)}$ *; where P = weight of the straw of the useful plot.*

Measurements of physical and chemical parameters of the soil

A basic sample was taken before the plots were put into cultivation. It consisted of taking samples at a depth of 20 cm at 5 points on the two diagonals of the total plot to constitute a single composite sample. Soil samples were taken on the horizon 0-20 cm per elementary plot. A total of 37 samples (12 samples x 3 plots + 1 before cultivation) were involved in the soil analyses. The analyses concerned pH, assimilable phosphorus (P-ass), organic carbon (C), total nitrogen (N-total) and available potassium (K-available). They were carried out at INERA's Soil-Water-Plant Laboratory. The pH was measured from a suspension of soil in water by the electrometric method with a glass electrode pH meter (AFNOR, 1999). The organic carbon content was determined according to the method of Walkley and Black (1934). Organic matter content was determined from organic carbon using the multiplier of 1.724 (Keeney and Nelson, 1982). Determination of total nitrogen (N-total) and available potassium (K-available): the samples are digested in a mixture of sulfuric acid, selenium and hydrogen peroxide (H_2SO_4-Se-H_2O_2) at 450°C for 4 hours, according to the method of Walinga *et al.* (1995). Assimilable phosphorus (P-ass) was extracted using the Bray-1 method (Bray and Kurtz, 1945).

Sum of exchangeable bases (S)

This is the amount of useful ions (Ca^{2+}, Mg^{2+}, K^+, Na^+) in the soil. The values of the exchangeable bases were obtained through displacement by a thiourea silver solution $Ag(H_2CSNH)_2$ at 0.01 M and determined by spectrophotometry.

Cation exchange capacity (CEC)

This is the maximum amount of cations that a given amount of soil can hold. It is expressed in $cmolc.kg^{-1}$. The higher the soil is rich in clay and humus.

Saturation rate (V)

It is the ratio of the sum of the exchangeable bases to the cation exchange capacity and corresponds to the percentage of the electronegative sites of the cation exchange capacity occupied by the exchangeable bases.

Data processing and analysis

The data collected were previously entered and processed using the Microsoft Excel 2016 spreadsheet, which was also used in the creation of the tables and graphs. R software version 4.3.2 was used for the data analysis. The comparison of the means was carried out at the significance level of 5% according to the Student-Newman-Keuls test.

Résults

Effects of tillage and fertilization on soil chemistry

pH, organic carbon (C_Org) and C/N ratio

The pH, organic carbon and the carbon to nitrogen ratio of the soil before cultivation and according to the treatments are presented in Table 2. In general, statistical analysis showed no significant difference between treatments. However, before cultivation, the soil was acidic (pH=5.55) with a low organic carbon content (0.45%) and a C/N ratio of 11.

Table 1. Coding of processing operations.

Treatments	Contributions	
T0	Fertilizer-free	-
T1	5 t/ha of compost	Spreading compost five days before sowing.
T2	5 t/ha of compost + 100 kg/ha of NPK + 50 kg/ha of urea	Spreading the compost five days before sowing, Application of the NPK to the 14th JAS, Application of urea at the 45th JAS.

The various types of tillage such as ploughing and subsoiling have made it possible to reduce the acidity of the soil very slightly (LM, pH=5.61; SSM, pH=5.66) as well as fertilization with T1 (pH=5.68) and T2 (pH=5.58). As far as the level of organic carbon is concerned, compared to that of the pre-crop, the different treatments (tillage and fertilization) have led to an average decrease ranging from 0.06 to 0.03% depending on the treatments. The C/N ratio ranged from 10.92 to 11.11 depending on the type of tillage, with the highest average for subsoiling (11.11) and the lowest for scarification (10.92).

For fertilization, this ratio varied between 10.95 and 11.06, with the highest value recorded at the T1 level (11.06) and the lowest at the T2 level (10.95).

Table 2. Effects of tillage and fertilization on pH, organic carbon and C/N ratio.

Parameters		pH_	Carbon	C/N
			%	
Before culture		5,55	0,45	11
Tillage	LM	5.61 ± 0.23	0.39 ± 0.07	10.95 ± 0.48
	SM	5.54 ± 0.30	0.44 ± 0.07	10.92 ± 0.40
	SSM	5.66 ± 0.25	0.43 ± 0.05	11.11 ± 0.44
	Pr(>F)	0,503	0.225	0.53
	Signification	NS	NS	NS
Fertilization	T0	5.55 ± 0.32	0.41 ± 0.07	10.97 ±0.50
	T1	5.68 ± 0.24	0.44 ± 0.07	11.06 ± 0.43
	T2	5.58 ± 0.20	0.42 ± 0.06	10.95 ± 0.41
	Pr(>F)	0.472	0.673	0.82
	Signification	NS	NS	NS
Tillage x Fertilization	Pr(>F)	0.8368	0.8606	0.3275
	Signification	NS	NS	NS

Legend: Pr: observed probability, NS: not significant. LM: Mechanized ploughing; SM: manual scarification; SSM: mechanized subsoiling. T0: no fertilizers; T1: 5 t/ha of compost; T2: 5 t/ha of compost + 100 kg/ha of NPK + 50 kg/ha of urea. pH: hydrogen potential; C_Org: organic carbon; C/N: carbon to nitrogen ratio.

Total nitrogen (N-total), available phosphorus (P_ass) and available potassium (K_disp)

Table 3 shows the total nitrogen content, available phosphorus and potassium available before cultivation and according to treatments. Statistical analysis indicates a significant difference (p=0.0213) between the different types of tillage in terms of available phosphorus. The concentrations varied on average between 17.54 and 26.10 mg/kg depending on the type of tillage, with the highest concentrations at the level of manual scarification, followed by subsoiling (20.23 mg/kg). Compared to the available pre-crop phosphorus content (3.77 mg/kg), tillage resulted in an increase in available phosphorus content ranging from 365.25 to 592.30% depending on the type of tillage. However, the various fertilizations did not have a significant effect on the available phosphorus but allowed an increase in its content of the order of 444.56 to 451.72% depending on the fertilizer applied compared to its content before cultivation. For total nitrogen, even if the statistical analysis did not show a significant difference between the different treatments, compared to the rate before cultivation, we note a decrease in this rate between 0.001 and 0.005% depending on the type of tillage.

Table 3. Effects of tillage and fertilization on total nitrogen, available phosphorus and available soil potassium.

Parameters		Nitrogen	Phosphorus	Potassium
		%	mg/kg	mg/kg
Before culture		0,041	3,77	63,1
Tillage	LM	0.036 ± 0.006	17.54[c] ± 4.32	62.40 ± 11.35
	SM	0.040 ± 0.006	26.10[a] ± 9.45	68.20 ± 11.58
	SSM	0.039 ± 0.004	20.23[b] ±7.14	63.06 ± 7.01
	Pr(>F)	0.17	0.0213 *	0.326
	Signification	NS	S	NS
Fertilization	T0	0.037 ± 0.006	20.53 ± 8.36	60.35 ± 12.83
	T1	0.040 ± 0.006	20.80 ± 5.43	67.25 ± 8.86
	T2	0.038 ± 0.004	20.57 ± 9.93	66.06 ± 7.82
	Pr(>F)	0.723	0.801	0.215
	Signification	NS	NS	NS
Tillage x Fertilization	Pr(>F)	0.8659	0.8166	0.7127
	Signification	NS	NS	NS

NB: The values followed by the same letter in each column are not statistically different at the 5% threshold according to the Student-Newman-Keuls (SNK) test: Pr: observed probability; NS: not significant; S: significant. LM: Mechanized ploughing; SM: manual scarification; SSM: mechanized subsoiling. T0: no fertilizers; T1: 5 t/ha of compost; T2: 5 t/ha of compost + 100 kg/ha of NPK + 50 kg/ha of urea. N_total: total nitrogen; P_ass: assimilable phosphorus; K_disp: available potassium.

The same is true for fertilization, with a decrease of between 0.001 and 0.004% depending on the type of fertilization applied. For the available potassium, the concentrations varied on average between 62.40 mg/kg and 68.20 mg/kg depending on the type of tillage.

Compared to the content before cultivation, slight decreases of 1.10% and 0.06% were observed respectively in ploughing and subsoiling, compared to an increase of 8.08% for scarification. This observation is also made in terms of fertilization, with an average decrease of 4.35% for Q0 and an average increase of 4.69 and 6.57% respectively for Q2 and Q1.

Exchangeable bases, cation exchange capacity (CEC) and saturation rate (V)

Table 4 presents the state of exchangeable bases, cation exchange capacity and base saturation rate prior to culture and for treatments. No significant differences were found between tillage types for the different tradable bases. However, compared to pre-cultivation levels, tillage resulted in a decrease of 0.06 to 0.07 cmolc.kg-1 in Ca^{2+} and 0.13 to 0.1 cmolc.kg-1 in Mg^{2+}. On the other hand, the K^+ and Na^+ contents remained stable. As for the cation exchange capacity (CEC), it varied from 2.38 to 2.48 depending on the type of tillage. However, there is a slight decrease due to tillage compared to that before cultivation. In fact, there were average decreases of

0.38 cmolc.kg-1 for ploughing, 0.35 cmolc.kg-1 for scarification and 0.45 cmol.kg-1 for subsoiling. As for the saturation rate (v), the different types of tillage allowed an increase (between 0.81 and 1.62%) compared to before cultivation. The best rate was recorded in subsoiling (49.74%), followed by manual scarification (49.21%). As with tillage types, no significant differences were observed in fertilization for exchangeable bases, CEC and saturation rate.

The various treatments also led to a slight decrease in Ca2+ and Mg2+ contents, ranging from 0.04 to 0.09 cmolc.kg-1 and 0.08 to 0.016 cmolc.kg-1 respectively, compared to the levels before culture.

Table 4. Effects of tillage and fertilization on tradable bases, CEC and soil saturation.

Parameters		Ca	Mg	K	Na	SBE (S)	CEC	V
		($cmolc.kg^{-1}$)	($cmolc.kg^{-1}$)	($cmolc.kg^{-1}$)	($cmolc.kg^{-1}$)	($cmolc.kg^{-1}$)	($cmolc.kg^{-1}$)	(%)
Before culture		0,71	0,41	0,16	0,09	1,36	2,83	48,12
Tillage	LM	0.64 ± 0.19	0.31 ±0.12	0.16 ± 0.03	0.09 ± 0.01	1.20 ± 0.22	2.45 ± 0.21	48.93 ± 6.97
	SM	0.63 ± 0.11	0.31 ±0.12	0.17 ± 0.03	0.10 ± 0.02	1.22 ± 0.19	2.48 ± 0.21	49.21 ± 7.27
	SSM	0.65 ± 0.10	0.28 ±0.13	0.16 ± 0.02	0.09 ± 0.02	1.18 ± 0.19	2.38 ± 0.20	49.74 ± 7.74
	Pr(>F)	0.944	0.766	0.326	0.511	0.932	0.552	0.964
	Signification	NS	NS	NS	NS	NS	NS	NS
Fertilization	T0	0.62 ± 0.12	0.25 ± 0.15	0.15 ± 0.03	0.09 ± 0.02	1.12 ± 0.20	2.40 ± 0.22	46.88 ± 9.42
	T1	0.67 ± 0.16	0.31 ± 0.09	0.17 ± 0.02	0.09 ± 0.01	1.25 ± 0.21	2.51 ± 0.21	49.67 ± 6.38
	T2	0.63 ± 0.12	0.33 ± 0.09	0.17 ± 0.02	0.10 ± 0.02	1.24 ± 0.17	2.40 ± 0.19	51.34 ± 4.61
	Pr(>F)	0.680	0.214	0.215	0.629	0.215	0.379	0.311
	Signification	NS	NS	NS	NS	NS	NS	NS
Tillage x Fertilization	Pr(>F)	0.3499	0.7439	0.7127	0.2219	0.2546	0.1157	0.8349
	Signification	NS	NS	NS	NS	NS	NS	NS

Legend: Pr: observed probability; NS: Not significant. LM: Mechanized ploughing; SM: manual scarification; SSM: mechanized subsoiling. T0: no fertilizers; T1: 5 t/ha of compost; T2: 5 t/ha of compost + 100 kg/ha of NPK + 50 kg/ha of urea. Ca: calcium; Mg: Magnesium; K: Potassium; Na: Sodium; S: Sum of tradable bases; CEC: Cation Exchange Capacity; V: Saturation rate.

The K+ and Na+ contents remained more or less stable within 0.01. For the CSC, it varied 2.40 to 2.51 cmolc.kg-1 depending on the treatment. There was a decrease of 0.43 cmolc.kg-1 for the T0 and T2 treatments, and a decrease of 0.32 cmolc.kg-1 for T1. The rate of saturation of the soil in cations varied between 46.88 and 51.34% depending on the treatments. The T1 and T2 treatments allowed a slight improvement in this rate of 1.55% for T1 and 3.22% for T2 compared to that before culture.

Weight of 1000 grains of sorghum

Table 5 presents the results of statistical analyses of the effect of tillage and fertilization on the weight of 1000 grains of sorghum. These results show a very highly significant difference (p= 0.00039) between the types of tillage on the weight of 1000 grains. The best average weight (21.08 g) was recorded in mechanized subsoiling, followed by mechanized ploughing with 20.58 g and finally, manual scarifying with 18.92 g as average weight. The statistical analysis shows a highly significant difference (p= 0.003) between the different fertilizations for the weight of 1000 grains. The T2 treatment (organo-mineral fertilization) recorded the highest average weight with 21.25 g and the lowest T0 treatment with 19.25 g.

The interaction between tillage and fertilization did not show a significant difference.

Sorghum yields

The results of statistical analyses of the effects of tillage and fertilization on sorghum yields are presented in Table 6.

Table 5. Effects of tillage and fertilization on the weight of 1000 grains of sorghum.

Parameters		1000 grit weight (g)
Tillage	LM	$20.58^{a} \pm 1.08$
	SM	$18.92^{b} \pm 1.24$
	SSM	$21.08^{a} \pm 1.37$
	Pr(>F)	0.000392 ***
	Signification	THS
Fertilization	T0	$19.25^{b} \pm 1.29$
	T1	$20.08^{ab} \pm 1.68$
	T2	$21.25^{a} \pm 0.87$
	Pr(>F)	0.003 **
	Signification	HS
Tillage x Fertilization	Pr(>F)	0.7467
	Signification	NS

NB: The values followed by the same letter in each column are not statistically different at the 5% threshold according to the Student-Newman-Keuls test (SNK): Pr: observed probability, NS: not significant S: significant; HS: Highly significant. LM: Mechanized ploughing; SM: manual scarification; SSM: mechanized subsoiling. T0: no fertilizers; T1: 5 t/ha of compost; T2: 5 t/ha of compost + 100 kg/ha of NPK + 50 kg/ha of urea.

Grain yield

For the grain yield of sorghum, the statistical analysis shows a highly significant difference (p= 0.00246) between the types of tillage. The highest grain yield (1497.49 kg.ha^{-1}) was obtained by mechanized subsoil, followed by mechanized ploughing (1477.64 kg/ha). Compared to manual scarification, subsoiling and ploughing resulted in an average yield gain of 438.94 and 419.09 kg.ha^{-1}, respectively. As with tillage, the analysis of variance showed a very highly significant difference (p= 0.00000112) for fertilization. Treatment T2 (organo-mineral fertilization) recorded the highest yield (1695.14 kg.ha^{-1}) and treatment T0 the lowest yield (1022.86 kg.ha^{-1}). Organo-mineral fertilization recorded an average yield of 379.46 kg/ha more than organic fertilization (T1). However, the interaction between tillage and fertilization did not show a significant difference.

Straw yield

The results of the statistical analyses show a significant difference (p= 0.0181) between the types of tillage for the straw yield of sorghum. Subsoiling stood out from the others by recording the highest average straw yield with 4540.60 kg/ha, although it is not statistically different from that of ploughing (4453.69 kg.ha^{-1}).

On the other hand, manual scarification recorded the lowest straw yield with 2669.71 kg.ha^{-1}, i.e. about 70.1% and 66.82% less respectively per subsoil and ploughing. For fertilization, statistical analysis shows a highly significant difference (p= 0.00431) between the different treatments. Treatment T2 (organo-mineral fertilization) recorded the highest average straw yield with 5101.60 kg.ha^{-1} and treatment T0 (without fertilizer) the lowest average yield with 2682.75 kg.ha^{-1}. Compared to organic fertilization (T1), organo-mineral fertilization allowed an average gain in straw yield of 1222.12 kg.ha^{-1}, an average increase of 31.50%. The interaction between tillage and fertilization did not show a significant difference.

Discussion

Effects of tillage and fertilization on soil chemical parameters

The pH values for water ranged from 5.54 to 5.68. Recent studies carried out on the same site by Tibi

(2023), confirm the acidic nature of the soil. In addition, Pallo *et al.* (2009) showed the acidic or slightly acidic nature of the tropical ferruginous soils found in Burkina Faso. Nevertheless, the various treatments have made it possible to raise the pH of the soil very slightly, from 5.55 to 5.68 depending on the treatments, with the best averages for mechanized subsoiling and organic fertilization. These results could be explained by the effect of subsoiling, which, by promoting water infiltration, would keep the soil moist. Ciesielski *et al.* (2008) noted a preponderant influence of organic carbon on the evolution of soil pH following an addition of calcium carbonate. Just like the work of Akanza *et al.* (2014) has shown that an addition of manure can solve the problems of drops in organic matter content and acidification.

Table 6. Effects of tillage and fertilization on sorghum yields.

Parameters		Grain yield (kg.ha^{-1})	Straw yield (kg.ha^{-1})
Tillage	LM	1477.64^{a} ± 340.27	4453.69^{a} ± 297.46
	SM	1058.55^{b} ± 257.92	2669.71^{b} ± 317.27
	SSM	1497.49^{a} ± 350.64	4540.60^{a} ± 669.05
	Pr(>F)	0.00246 **	0.0187 *
	Signification	HS	S
Fertilization	T0	1022.86^{c} ± 212.37	2682.75^{b} ± 131.74
	T1	1315.68^{b} ± 220.61	3879.48^{ab} ± 113.21
	T2	1695.14^{a} ± 312.52	5101.60^{a} ± 219.99
	Pr(>F)	0.00000112 ***	0.00431 **
	Signification	THS	HS
Tillage x Fertilization	Pr(>F)	0.2441	0.9907
	Signification	NS	NS

NB: The values followed by the same letter in each column are not statistically different at the 5% threshold according to the Student-Newman-Keuls (SNK) test.

Legend: Pr: observed probability, NS: not significant S: significant; HS: Highly significant. LM: Mechanized ploughing; SM: manual scarification; SSM: mechanized subsoiling. T0: no fertilizers; T1: 5 t/ha of compost; T2: 5 t/ha of compost + 100 kg/ha of NPK + 50 kg/ha of urea.

The treatments resulted in a slight decrease in organic carbon content compared to its status prior to culture. These results could be due to the fact that deep tillage such as ploughing and subsoiling. The organic carbon content was higher in manual scarification compared to other tillage. Similar results were obtained by Abdellaoui *et al.* (2010) who noted that organic matter accumulates widely with no-till and simplified techniques compared to ploughing in a study conducted in Algeria. Our results disagree with those obtained by Tibi (2023) who had shown a slight increase in organic carbon content in maize crops on the same site but with higher amounts of OM (organic matter) added. The C/N ratio before culture and those of treatments changed very little. They ranged from 10.92 to 11.11. This reflects a good decomposition of organic matter (Bassolé *et al.*, 2023). Similar results were obtained by Tibi (2023) at the same site with values ranging from 8.53 to 9.95. Mechanized ploughing and manual scarification recorded the lowest C/N ratios. This testifies to their effects on the rate of humus mineralization, which is often not necessarily synchronized with the needs of the plants (Sana, 2018). However, according to N'Dayegamiye *et al.* (2007), soil nitrogen is mainly found in organic form. Therefore, a decrease in the C/N ratio indicates an improvement in the activity of microorganisms, thus promoting the decomposition of organic matter. Nitrogen levels in all treatments remained very slightly lower than pre-crop levels. The nitrogen levels of the manual scarification and organic fertilization treatments remained very close to the pre-crop level within 0.001. This would be linked to manual scarification of the soil; This promotes the concentration of nitrogen in the first few centimetres of the soil. D'Haene *et al.* (2008) note that nitrogen nitrate concentrations in systems that include minimum tillage were generally higher in the top 10 cm of soil compared to ploughed soil. But also, to the organic manure applied because compost is an important source of organic matter and food for soil microorganisms, thus promoting the availability of nutrients (Yameogo *et al.,* 2013). Tillage significantly influenced (p=0.0124) the assimilable phosphorus content of the soil, with the best content obtained at the level of manual scarification followed by subsoiling. These results could be explained by the low mobility of this element, thus allowing its accumulation, especially when the soil is subject to low disturbances, as in the case of manual scarification. Indeed, according to Lacharme (2001), phosphorus is not very mobile in the soil and has the ability to attach to the soil absorbent complex, thus allowing its accumulation. For fertilization, it is the organo-mineral fertilization that has the high assimilable phosphorus content. This could be because compost is an important source of organic matter and soil nutrients such as phosphorus. It is also a source of energy and food for soil microorganisms, thus promoting the availability of nutrients (Yaméogo *et al.,* 2013). As a result, its contribution makes it possible to increase the nutrient capacity of the soil, hence the increase in the level of available nutrients, in this case assimilable phosphorus, as previously observed by Akanza and Yoro (2009) in Côte d'Ivoire. Available potassium concentrations varied very little between treatments and compared to pre-culture. This could be explained by the intake of potassium from mineral and organic sources, thus helping to maintain and even increase its contents. According to CILSS (2001), although the soils of Sahelian countries are very poor in organic matter, nitrogen and phosphorus, potassium is often fairly well represented. In terms of soil work, it was manual scarification that allowed a slight increase in available potassium. This shows that deep tillage (mechanized ploughing and scarification) would not be favourable to the availability of potassium. Our results are in agreement with those found by Garané *et al.* (2017) who found higher concentrations of available potassium on the 0-20 cm minimum tillage layer (8 cm deep) compared to minimum tillage (20 cm deep) and conventional tillage (30 cm deep) in the "non-chernozem" non-black soil zone of the Russian Federation. For fertilization, it was the T1 (organic) and T2 (organo-mineral) treatments that led to an increase in available potassium compared to the pre-culture content. The compost and mineral fertilizers provided are a source of nutrients for the soil such as potassium, but also a source of energy and food for soil microorganisms, thus promoting the availability of nutrients (Yaméogo *et al.,* 2013). Our results are in agreement with those of Koulibaly (2011) who found that fertilizer applications improve the available potassium content of the soil while enriching the soil with nutrients. However, he points out that potassium can only be assimilated if the $K+$ ions are not too strongly bound to the clays. The sum of the exchangeable bases after culture ranged from 1.18 to 1.25 cmolc.kg-1 depending on the treatment. This could be linked to the non-restitution of organic waste to compensate for losses due to mineralization, thus leading to a rapid decrease in the rate of organic matter with a decrease in the contents of exchangeable bases, cation exchange capacity, acidification of the soil and an increase in exchangeable aluminum content (Mills and Fey, 2003). Similar results were found by Tibi (2023) at the same site with a sum of exchangeable bases that varied between 1.38 and 2.14 cmolc.kg-1 depending on the treatments. The values of cation exchange capacity obtained before and after culture were very low (2.38 to 2.83 cmolc.kg-1). These results could be explained by the low levels of organic matter and clay, as CEC is closely linked to these two elements. Indeed, in addition to the low organic matter content (0.72 to 0.77%), the results of the three-fraction soil particle size analysis of our study site also confirm the low clay content (14.36%). Our results are in agreement with those obtained by Koulibaly (2011) who showed that the low cation exchange capacity is a good indicator of soil vulnerability to acidification, as it conditions the buffering capacity of the soil, which depends on its clay and organic matter contents. The saturation rate varied between 46.88 and 51.34% depending on the treatments. This is considered average according to the BUNASOLS interpretive standards. Similar results (46%) were obtained by Bassolé *et al.* (2023) on tropical ferruginous soils leached in the Goundi-Djoro lowlands in central-western Burkina Faso. In addition, Tibi (2023) had found an average saturation rate (56.10%) according to BUNASOLS standards on the same site. To compensate for this low saturation rate, large base inputs by liming could make it possible to compensate for losses due to exports or erosion, to increase the saturation rate of the complex and thus avoid the fixation of acid ions on the adsorbent complex.

Effects of tillage and fertilization on agronomic parameters of sorghum

Statistical analyses showed significant to very highly significant differences for 1000 grain weight, grain and straw yields of sorghum between the different types of tillage. The best performance in terms of grain and straw yields as well as the weight of 1000 grains are obtained with mechanized subsoiling and mechanized ploughing. Mechanized subsoiling and mechanized ploughing promote good grain filling compared to manual scarification. Our results are in agreement with those obtained by Traoré (2012) who had obtained higher yields of grain and straw of sorghum with ploughing compared to manual scarification. In addition, Jiao *et al.* (2017) showed that subsoiling in maize cultivation is likely to create favourable growing conditions by increasing the water content as well as the permeability of the soil and therefore the yield. Our results are also similar to those obtained by Shen *et al.* (2021) who obtained with subsoiling a higher maize yield as well as a positive effect on the weight of 1000 grains. In the same vein, the work of Palé *et al.* (2021) has shown that ploughing has a beneficial effect in improving soil structure and the development of the plant's root system and therefore its productivity. This allowed the latter to have substantial increases in grain yields from 266 to 635 kg/ha and straw yields ranging from 381 to 601 kg/ha compared to manual scarification, ridge and manual zaï in millet cultivation. Organo-mineral fertilization showed the best performance in terms of grain and straw yields. These results are due to the ability of the combination of compost and mineral fertilizers to act favorably on the different soil parameters. Our results are similar to those obtained by Traoré *et al.* (2021) who found higher yields of grain (1475 $kg.ha^{-1}$) and straw (5227 $kg.ha^{-1}$) of sorghum with treatments combining compost with popularized mineral fertilizer compared to mineral fertilization alone (1039 $kg.ha^{-1}$ and 2528 $kg.ha^{-1}$) in western Burkina Faso. The work conducted by Palé *et al.* (2021) also showed that the application of mineral fertilizers associated with compost increased the grain yield of millet compared to mineral fertilization alone. Indeed, according to Hien (2004), the positive effect of organo-mineral fertilization on crops results from the improvement of the organo-mineral status of the soil and its probable interaction on the physical properties of the soil, including the water status. The low grain and straw yields observed at the T0 level (without fertilization) would be attributed to a low nutrient availability on soils already poor in organic matter. These results confirm the essential role of the combined use of mineral and organic manure to enable the efficient use of nutrients provided in the form of fertilizers in agrosystems in Burkina Faso, as reported by Zeinabou *et al.* (2014). It is on the basis of these findings that Koulibaly *et al.* (2015) proposed that, if the production potential is not maintained, burying residues on the ground and recycling them into organic manure, combined with mineral manure, reduces the decline in yields linked to continuous land use.

Conclusion

The grain and straw yields of sorghum as well as the weight of 1000 grains have been significantly improved by tillage and fertilization. The best yields were obtained by mechanized subsoiling and mechanized ploughing. Organo-mineral fertilization also gave the best yields. Tillage and organo-mineral fertilization significantly improve sorghum yields. The study found that subsoiling and ploughing combined with organo-mineral fertilization provide the best yields of sorghum. However, the effect of these practices on the physicochemical parameters of the soil has been unsatisfactory. In addition, a practice such as subsoiling is more efficient on compacted soils or in order to break the plough footings. In perspective, it would be interesting to continue the study over several years, in order to better understand the long-term effects of these agricultural practices studied on sorghum yields and fertility.

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