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Effects of soil preparation techniques and organic-mineral fertilization on maize (*Zea mays* L.) yields in western Burkina Faso in the context of climate change

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ABSTRACT

Soil preparation remains a very important operation on degraded soils subject to current rainfall deficits in the Sahel. In order to find solutions to strengthen farmers' resilience, a study was conducted at Farako-Bâ research Center in Burkina Faso to assess the impact of tillage and fertilization options on maize yields. To this end, a split-plot experimental design was set up with soil preparation techniques as the main factor with 3 levels three : no-till, tillage, ridging; and the fertilization as secondary factor with four levels: T1: Control, no fertilizer; T2: 5 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea; T3: 10 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea; T4: 200 kg/ha of NPK + 100 kg/ha urea (recommended mineral by extension service). Data collection was focused on soil chemical parameters, maize grain and biomass yields. The results showed that ridging provided the best grain (1807 kg/ha) and biomass (2074 kg/ha) yields, followed by tillage with 1110 kg/ha and 1340 kg/ha, respectively for grain and biomass. Organo-mineral fertilization generated the best results, with a grain yield of 2041 kg/ha for treatment T3 and 1635 kg/ha for treatment T2. Data showed positive interaction between soil preparation technique and fertilization for ridging and organo-mineral fertilization, with grain yields of 3462 kg/ha and 1972 kg/ha for treatments T3 and T2, respectively. The ridging appears to be a strategy for good management of soil nutrients and water in conditions of low rainfall in Burkina Faso.

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INTRODUCTION

Burkina Faso's economy is based primarily on agriculture, which employs more than 86% of its working population (MAHRH, 2011). Crop production is mainly family-based and dominated by cereal production, which forms the basis of the population's diet. Among these cereals, maize is ranked first in terms of production since 2020. The total production of maize in 2021 was estimated at 1,913,000 tons, which is 41% of total cereal production. Maize is ahead of sorghum previously ranked as first cereal , with 1,617,000 tons , and representing 34% of total production (MAAH, 2021; FAO, 2023).

Despite its importance, maize cultivation, like the other cereals grown in Burkina Faso, faces many constraints leading to decline in yields despite the use of improved varieties (Bassole *et al.*, 2023). Among the constraints, unappropriated farming practices, has led to continuous decline in soil fertility under changing climate conditions (Dabré *et al.*, 2016). Despite the original poverty of the soil in nutrients, crop production in Burkina uses low quantities of mineral fertilizers and has low organic manure application (DSS, 2020; Konkobo *et al.,* 2023). This farming practice has led to accelerated degradation of agricultural lands with negative nutrient balances and the declining crop productivity (Drabo, 2009). In addition to these soil constraints, rainfall patterns are becoming increasingly unpredictable due to the adverse effects of climate change (Nacro *et al.,* 2010; Traoré *et al.*, 2021). As crop production is mainly rain-fed, the rainy seasons are highly variable, punctuated by drought spells which do not always guarantee good harvests. In view of all above, it is important to look for sustainable solutions for integrated soil fertility management and good soils and water management practices at the field level so that crops can complete their growth cycle with higher productivity. Among the soil cultivation techniques used in Burkina Faso, flat plowing remains by far the eldest and most widely practiced used by farmers. Other techniques such as ridging and no tillage are also used by farmers for various reasons, including lack of agricultural equipment and late onset of rains. Each of these soil preparation techniques has advantages and constraints, and some may be better suited to current rainfall pattern. It should be noted that tillage is prohibited in the case of conservation agriculture because of its contribution to soil erosion and other consequences on the decline in physical, chemical, and biological characteristics (Séguy *et al.*, 2007; Djamen *et al.*, 2014). Adaptation to the adverse effects of climate change includes actions at field-level in soil and water management techniques and the use of organic fertilizers (Hounzinme *et al.,* 2017). Given the increasingly changes in rainfall patterns in the country, there is an urgent need to propose better practices and this can include soil preparation technique combined to adequate organic-mineral fertilization methods as a strategy to adapt to climate change and improving soil fertility at the field level in a main objective of increasing maize production in Burkina Faso.

MATERIALS AND METHODS

Study site

The study was carried out during the rainy seasons of 2020 and 2021 in INERA/Farako-Bâ agricultural research center, located at longitude 4° 20' West, latitude 11° 6' North, and altitude 405 m. The research center is located in the south Sudanian climatic zone of Burkina Faso, characterized by two distinct seasons: a short rainy season from June to September and a long dry season from October to May. Average annual rainfall varies between 800 and 1100 mm (PANA, 2007) with unevenly spatial and temporal distribution. The amount of rainfall recorded at Farako-Bâ station in 2020 and 2021 was 1,223 mm in 71 days and 1,221 mm in 72 days, respectively. The soils of the site are ferruginous tropical leached soils with a sandy-loamy texture, poor in organic matter and major nutrients (N, P, K) (*Da et al.*, 2019). The most frequently vegetation woody species encountered in the trial site are: *Daniellia oliveri* (Rolfe) Hutch. and 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).

Plant material

The plant material used in the trials was maize variety "*Barka*" developed by the INERA/Burkina Faso Research Institute. The variety has white grain colors with an average planting-maturity cycle of 84 days. the variety is indicated to be relatively drought-tolerant with potential grain yield of 5.5 t/ha.

Mineral fertilizer

The mineral fertilizer used was NPK compound fertilizer with formulation 14-23-14+6S+1B and urea 46% N t. These fertilizers are recommended by agricultural research, commonly found in the local markets, and used by farmers in Burkina Faso for maize production.

Organic fertilizer

The organic fertilizer used was compost produced by aerobic composting in piles using maize stover and cattle manure as an activator.

Experimental design

The trials were conducted in a split-plot design with completely randomized blocks and four (4) replicates. The main factor was the soil preparation technique with three levels of variation (zero tillage, tillage, and ridging), and the secondary factor was fertilization, with four (4) levels of variation (Table 1). The blocks were separated by 2 m space and the unit plots of 25 m^2 (5×5 m) plots were separated by 1 m space.

Table 1. Treatments used in the experimental design

Main factors (soil preparation techniques)	Secondary factors (fertilization)
No tillage and direct sowing (NT)	T1 : Control, no fertilizer T2 : 5 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea; T3 : 10 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea; T4 : 200 kg/ha of NPK + 100 kg/ha urea (recommendation from extension)
Tillage (TL)	T1 : Control, no fertilizer T2 : 5 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea; T3 : 10 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea; T4 : 200 kg/ha NPK + 100 kg/ha urea (recommendation from extension)
Ridging (RG)	T1 : Control, no fertilizer T2 : 5 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea; T3 : 10 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea; T4 : 200 kg/ha NPK + 100 kg urea (recommendation from extension)

Soil preparation techniques

No tillage (NT): plot not undergone any preparation. Sowing is done after total herbicide (with Paraquat), is sprayed.

Tillage (TL): the land is plowed by cattle at depth of 15 to 20 cm. The strips are turned over on the same side.

Ridging (RG): was carried out using a cattle-drawn ridger and consisted of turning over the strips of soil in pairs to form a ridge.

Sowing

Sowing was done manually with density 80 cm between rows and 40 cm between planting pits for tillage plots and those with no tillage. For plots with ridges, sowing was done directly on the ridges with spacing of approximately 60 cm between ridges and 40 cm between pockets. The planting pits were thinned to two (02) plants per pocket for each type of soil preparation at 14 days after emergence.

Fertilization

Compost was applied as basal fertilizer (before sowing) at dose of 5 t/ha for all T2 treatments and 10 t/ha for all T3 treatments.

NPK was applied at dose of 200 kg/ha on the 15th day after sowing (DAS) for treatments T2, T3 and T4.

Urea was split in 2 applications: 50 kg/ha at 30th DAS and 50 kg/ha at 45th DAS.

Soil sampling and analysis

Soil samples were taken at depth 0-20 cm before land preparation, and composite samples were prepared for various chemical parameters analysis. The trial site was split in 3 zones based on soil physical characteristics and 3 composites samples were collected for analysis.

The pH water of the soil samples was determined by the electrometric method with a glass electrode pH meter in a soil/water ratio of 1/2.5 (AFNOR, 1999). The total carbon content was determined according to the method of Walkley and Black (1934) modified by Graham (1948). Total nitrogen was determined using Kjeldhal method (1883) by mineralization of organic matter. The nitrogen is transformed into ammonium sulphate and is collected by distillation and titrated to measure total nitrogen. Total phosphorus is measured directly on the condensed mineralization (Anderson and Ingram, 1989). The total potassium as well as the available potassium was determined by the method of flame spectrophotometry. The Bray I (Bray and Kurtz, 1945) method was used for the determination of soluble phosphorus in an extraction ratio of 1/7.

Harvesting and yield assessment

Plots yields (grain and biomass) were determined by harvesting alle the maize ears manually in the plots. The ears were sun dried for one week and shelling. The grains from the plot were weighed and used for yields determine. The plant biomass of each unit plot was cut, dried up and weighed.

The grain yield (Ygn):

Ygn (kg/ha)= {(Average treatment grain weight (kg))/(25 m²)}×10000 m²

The biomass yield (Ybm):

Ybm (kg/ha)= {(Average treatment biomass weight (kg))/(25 m²)}×10000 m²

Data processing and statistical analysis

All the data collected were entered in Excel 2016 spreadsheet and statistical analyses, tables and graphs were done using XLSTAT 2016 software. The signification the data was tested using the Kruskal-Wallis test, and the comparison of means was performed using the Student-Newman-Keuls test when the differences were significant at 5% threshold using XLSTAT 2016 software.

RESULTS

Soil chemical characteristics

Table 2 shows the results of soil chemical characteristics before application of the treatments. The soils pH water ranked between 5,50 and 5,90 with an average of (5.68. the lowest pH was found in sample 3. Soil organic matter, total Nitrogen, t showed the same trend as soil pH. Data show similar value for soluble P and K. and very low levels of major chemical elements (N, P, K) and minerals. They are also low in carbon with low levels of organic matter.

Effects of soil preparation techniques on maize grain and biomass yields

The results of the effects of tillage on maize grain and biomass yields are shown in Table 3. Analysis of variance revealed significant differences (p<0.05) between tillage techniques on maize grain and straw biomass yields. The ridge technique generated statistically higher grain (1807 kg/ha) and straw (2074 kg/ha) yields than tillage and no tillage. No tillage techniques recorded the lowest grain yield (639 kg/ha), but its straw yield was statistically equivalent to that of tillage.

Effects of organic fertilizer on maize grain and biomass yields

Table 4 shows maize grain and straw biomass yields according to fertilizer option. Analysis of variance shows that the treatments are significantly different (p<0.05). Treatment T3 (10 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea) generated statistically higher grain and biomass yields than treatments T2 (5 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea) and T4 with recommended mineral fertilizer (200 kg/ha of NPK + 100 kg/ha urea). Treatment T1, without fertilizer application, recorded the lowest grain and biomass yields, with 176 kg/ha and 408 kg/ha, respectively.

Table 2. Chemical characteristics before planting

	Chemical parameters						
	pH water	Org-C (%)	OM (%)	N-total (%)	C/N	P-Bray1 (mg/kg)	K-avail (mg/kg)
Sample 1	5,71	0,46	0,79	0,042	10,96	2,35	41,93
Sample 2	5,84	0,50	0,86	0,041	12,13	2,11	41,86
Sample 3	5,50	0,32	0,55	0,029	11,07	2,25	41,93
Average	5,68	0,43	0,73	0,037	11,39	2,24	41,91

Org-C : Organic carbon ; MO : Organic matter ; N-Total : Total nitrogen ; K-avail : Soluble Potassium; P-Bray 1: Soluble phosphorus

Table 3. Effect of soil preparation techniques on maize grain and biomass yields

Soil preparation techniques	Yields (kg/ha)	
	Grain	Biomass
Ridging	1807a	2074a
Tillage	1110b	1340b
No tillage (direct sowing)	639c	1161b
Pr>F	0.000	0.000
Significance	Yes	Yes

Note: Within the same column, values assigned the same letter are not significantly different according to Newman Keuls' multiple means comparison test at the 5% probability threshold.

Table 4. Effect of organic and inorganic fertilizer on maize grain and biomass yields

Treatments	Yields in kg/ha	
	Grain	Biomass
T1 : Control, no fertilizer	176d	408c
T2 : 5 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea ;	1635b	2098a
T3 : 10 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea ;	2041a	2307a
T4 : 200 kg/ha of NPK + 100 kg/ha urea (recommended mineral dose RMD)	889c	1288b
Pr>F	0.000	0.000
Significance	Yes	Yes

Note: Within the same column, values assigned the same letter are not significantly different according to Newman Keuls' multiple means comparison test at the 5% probability threshold.

Table 5. Soil preparation techniques and fertilization options on maize grain and biomass yields.

Soil preparation techniques * Fertilization	Yields in kg/ha	
	Grain	biomass
Ridging*T3	3462[a]	3560[a]
Ridging*T2	1972[b]	2347[b]
Tillage*T2	1881[b]	2164[b]
Tillage *T3	1498[bc]	1780[bc]
Ridging*T4	1467[bc]	1794[bc]
No Tillage*T3	1164[c]	1581[bcd]
No Tillage*T2	1053[c]	1784[bc]
Pr>F	0,000	0,000
Significance	Oui	Oui

Effects combined of effect of soil preparation techniques and fertilization options on maize grain and biomass yields

Table 5 shows the grain and straw biomass yields of maize under the combined effects of tillage technique and fertilization options. Statistical analysis reveals significant differences ($p<0.05$) between treatments in maize yields. Treatment T3 (10 t/ha compost + 200 kg/ha NPK + 100 kg/ha urea) applied to ridging statistically yielded the highest average grain and biomass yields. The next best options were ridging techniques combined with treatment T2 (5 t/ha compost + 200 kg/ha NPK + 100 kg/ha urea), The ridging combined with exclusive mineral fertilizer generate lower yields compared to ridging combined with organo-mineral fertilizer.

DISCUSSION

Effect of soil and fertilization options on maize yields

Analysis of soil samples from the study site reveals that trials sites are acidic and poor in most of the nutrients. All the values of the chemical parameters analyzed are below the deficiency standards reported by BUNASOLS (1990) but the data obtained are closed to those reported by Bado (2002), Da (2016). The soils of the trial site are poor in nutrients and The low values are thought to be due to the original nature of soils at the study site, which are tropical ferruginous soils, but also to farming practices that do not improve soil fertility. Pallo and Thiombiano (1989) describe tropical ferruginous soils as soils that are originally poor in nutrients, particularly phosphorus and organic matter. These soils are often sandy on the surface, with clay leaching tends to accumulate at depth closed to the clogged horizon.

Kaolinite-dominant clays confer low base capacity with slightly acidic pH levels that evolve with agricultural practices (Bassole *et al.,* 2023). With such initial constraints, poor farming practices can only accelerate their degradation given the low levels of the chemical parameters observed. The soils at our study site are subject to continuous exploitation without organic restitution, which has affected their fertility over the years. The same was reported by Da *et al.* (2020), who indicated that Farako-Bâ Research Center soils are sandy soils (78%), poor in nutrients, acidic, and low in organic matter. Our results corroborate those of Koulibaly *et al.* (2014), who indicate that the decline in carbon content in tropical ferruginous soils could be linked, at one hand, to the insufficiency or even lack of organic fertilizer input and, on the other hand, to the effect of climate change and tillage techniques, which leads to carbon loss through mineralization of organic matter and soil erosion which is characteristic of tropical areas of sub-Saharan Africa.

Statistical analyses reveal, that the soil preparation technique combined with different doses of organic fertilizer has a significant effect on grain and maize straw biomass yields. In terms of fertilization options, treatments T3 and T2, which combine mineral and organic fertilizers, generated the highest maize grain and biomass yields. Treatment T3 (10 t/ha of compost + 200 kg of NPK + 100 kg of urea) remains the most effective with the highest organic fertilizer dose of 10 t/ha of compost compared to treatment T2, which has the same mineral fertilizer dose but only 5 t/ha of compost. Both treatments T3 and T2 yield more grain and maize straw biomass than treatment T4, which contains only mineral NPK and urea fertilizers. These results show that adding organic fertilizer significantly increases maize yields compared to exclusive mineral fertilizer (NPK+urea). organic manure is reported to have a positive effect on soil physical, chemical, and biological properties.

As the soils at the trial site are acidic and poor in organic matter and nutrients (Da *et al.,* 2020), combining compost undoubtedly improved their properties and made the mineral fertilizers more efficient. The addition of organic manure improved the soil's water retention capacity and cation exchange capacity. The mineral fertilizer ions released are more readily fixed by the soil and can be easily taken up by crops. Because of the improved taken up capacities plant growth and development in treatments T2 and T3 were higher, resulting in higher grain and straw biomass yields. Similar results were obtained by Traore *et al.* (2022) with the addition of mineral fertilizers to different types of soil amendments, which resulted in higher tomato fruit yields. The slow release of soil organic matter, improves the mineral nutrition of the plant (Traore *et al.*, 2021). All reported effects of the organic matter justify the higher grain and straw biomass yields obtained with treatments T3 and T2 in our study. Bazongo *et al.* (2024), reported the effectiveness of organo-mineral fertilization with higher grain yield gains of 379.46 kg/ha compared to organic fertilization alone and 672.28 kg/ha compared to the control without fertilizer in a study on sorghum.

Effect of soil preparation techniques on maize yields

For soil preparation techniques, ridging has been the most effective, yielding the highest grain and biomass yields. Ridge involves bringing the soil together on a continuous ridge.

This technique has two major advantages: it reduces runoff and erosion (Xu *et al.*, 2018), and reduces nutrients losse and improves water retention on the plot (Parwada *et al.*, 2024). The favorable conditions created leads to better plant growth and development. Djoukeng (2016) reported that ridging is an anti-erosion technique that reduces soil loss and increases yields (Djoukeng *et al.*, 2015); and this was shown by our data. Similar results were obtained by Xu *et al.* (2018), Wang *et al.* (2024), and Parwada *et al.* (2024), who indicted higher nutrient accumulation and better water retention in partitioned ridge cultivation, resulting in best crop growth and yields. Our study showed that that organic-mineral fertilization combined with ridging is the most effective treatment, compared to tillage or no tillage. Similar results were obtained by Xu *et al.* (2018) and Wang *et al.* (2024), who found better water infiltration and crop growth conditions with partitioned ridge cultivation. Kouelo *et al.* (2012) indicated that tillage generally has a beneficial effect from the beginning of the crop cycle, with differences reaching their maximum at the time of cereal emergence. The soils of the trials site are encrusted and, without minimal tillage, water infiltration is difficult. This explains the low maize yields obtained with no tillage, especially when rainfall is poorly distributed with long periods of drought. Ridge cultivation therefore appears to be a solution to nutrient and water losses through runoff on the plot. The work of Ndung'u *et al.* (2023) confirms our results by showing that organic matter, water retention capacity, and corn yields in their study were better in ridging than in the control plots without ridging.

CONCLUSION

Fron the current study we can conclude that the ridging technique combined with organic-mineral fertilization (5 t/ha or 10 t/ha of compost + 200 kg/ha NPK + 100 kg/ha urea) generated significant higher maize yields compared to no-tillage and tillage with the same fertilizer doses. Our study also showed that the higher the organic manure dose , the better the crop growth. But because the mineralization rate and the availability of the sour of organic matter it can recommended the dose of 5 t/ha of compost. The effectiveness of ridging lies on it capacities to improve soil water and nutrients management thereby improving plant nutrition. As the study area is facing advanced soil degradation and increasingly poor rainfall conditions to adequately support crop cycles, ridge cultivation appears to be an effective fertility management technique and a strategy for adapting to climate change. The current study should be replicated under different soils physical characteristics for a better mapping of the appropriate soil preparation techniques for each soil and climatic conditions.

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