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Effects of locally sourced organic fertilizers on sorghum yield in Burkina Faso

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Abstract

Sorghum (*Sorghum bicolor*) is a crucial crop in Burkina Faso, holding a central position in the country's agriculture and food systems. It contributes to rural household incomes, particularly through the sale of surplus production. However, its culture faces significant challenges, with limited access to inputs being among the most critical. This study was initiated to evaluate the effects of organic fertilizers on sorghum yields and sustainable soil productivity in the East Sudanian zone of Burkina Faso. The objective was to contribute to improving soil fertility to sustainably enhance sorghum yields. The experiment was conducted in a completely randomized Fisher block design, consisting of two blocks. Bokashi treatment was applied in block 1, while local liquid fertilizer treatment was applied in block 2, with 4 replications and 6 and 7 treatments, respectively. The chemical properties of the organic fertilizers, soil macrofauna, yields, and their components were analyzed. The results showed that Bokashi had significant levels of organic matter, total nitrogen, total phosphorus, total potassium, and a highly alkaline pH compared to liquid fertilizer, which had lower nutrient levels. Bokashi had a C/N ratio of 32.6 with a basic pH. Observations indicated that all treatments yielded better results than the control. However, treatments T4 and T6 achieved the highest macrofauna densities, with 33 individuals/m^2 and 25 individuals/m^2, and diversity indices of 1.18 and 1.35, respectively. The highest average grain yields were achieved with treatments T2 (4525.2 ± 321.50 kg/ha), T1 (4153.5 ±488.27 kg/ha) and T6 (4086.0 ±319.00 kg/ha). These results suggest that organo-mineral fertilization is an effective approach to improve sorghum yields.

Keywords: Sorghum; Bokashi; Local Liquid Fertilizer; Soil Macrofauna; Yield; Burkina Faso

1. Introduction

In Burkina Faso, the agricultural sector employs over 80% of the working population, and its contribution to gross domestic product was estimated at 18.48% in 2021 [1]. Despite its importance, average yields of the main crops remain low, and stagnate over the years. In addition to the inherent unfavorable soil characteristics, inappropriate farming practices and low organic matter inputs are factors that aggravate the deterioration in the physical, chemical and biological quality of soils, leading to a reduction in their productive capacity [2]. Mineral fertilization is one of the practices commonly used by small-scale farmers to improve crop yields on poor soils. However, the high cost of fertilizers and their limited availability in production areas, limit their access in the quantities needed to effectively improve crop productivity [3].Chemical fertilizers are characterized by their effectiveness and immediate effect on crop yields due to their rapid dissolution in the soil. However, several research results have shown that the exclusive use of chemical fertilizers does not guarantee sustainable agricultural production. Indeed, the inappropriate use of chemical fertilizers can damage the environment [4]. Excessive use of mineral fertilizers also weakens plants and makes them vulnerable to insect and fungal attack. The exclusive application of mineral fertilizers is detrimental to soil quality, and is generally only effective during the first few years of continuous inputs [5]. This is followed by a drop in yield after a few years, due to the degradation of the soil's physico-chemical properties [5]. In addition, the use of chemicals

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significantly reduces soil biodiversity, which plays a vital role in soil life [6]. In view of all these adverse effects induced by chemical fertilizers, it is necessary to adopt new ways of managing soil fertility. There are many fertility management strategies that can sustainably maintain the productivity and fertility of cultivated soils. Organo-mineral fertilization plays a key role in these strategies. Indeed, sustainable fertility management requires the maintenance of a certain proportion of organic matter in the soil [7]. Organic matter ensures cohesion between the soil's physical elements stimulates microbial activity and supplies mineral elements through its biological, physical and chemical components [8]. [9] in Burkina Faso, have shown that combining organic fertilizer with mineral fertilizer limits the loss of soil organic matter, reduces soil acidification and increases crop yields. Organic amendments have also been shown to be effective in vegetable production [10]. Faced with this situation, organic fertilizers offer an opportunity to reduce the use of mineral fertilizers in agriculture. Several research results have shown that organic fertilizers help improve yields of several crops, notably tomato and onion [11, 12]. Among these organic fertilizers, compost, bokashi and liquid fertilizer have been the subject of several experiments. These composts have proven their effectiveness in agriculture. However, the real problem to date is the dosage and quantity of these fertilizers required per hectare. In view of the multiple advantages of organic fertilizers, they could contribute to a sustainable improvement in yields and soil fertility. This is undoubtedly the background to the present study entitled: “Effects of locally sourced organic fertilizers on sorghum yields in Burkina Faso”. The general objective of this study is to contribute to the improvement of soil fertility in order to sustainably increase sorghum yields. Specifically, it aims to: (i) determine the effects of organic fertilizers on sorghum yields; (ii) analyse the influence of organic fertilizers (organic manure, bokashi and liquid fertilizer) on soil macrofauna.

2. Material and methods

2.1. Site description

This study was carried out in the commune of Fada N'Gourma. The town of Fada N'Gourma, capital of the commune, province and region, is located 220 km from Ouagadougou. The commune of Fada N'Gourma lies between 0'7' west longitude and 1'25' east longitude, and 13'7' and 11'55' north latitude (Figure 1).

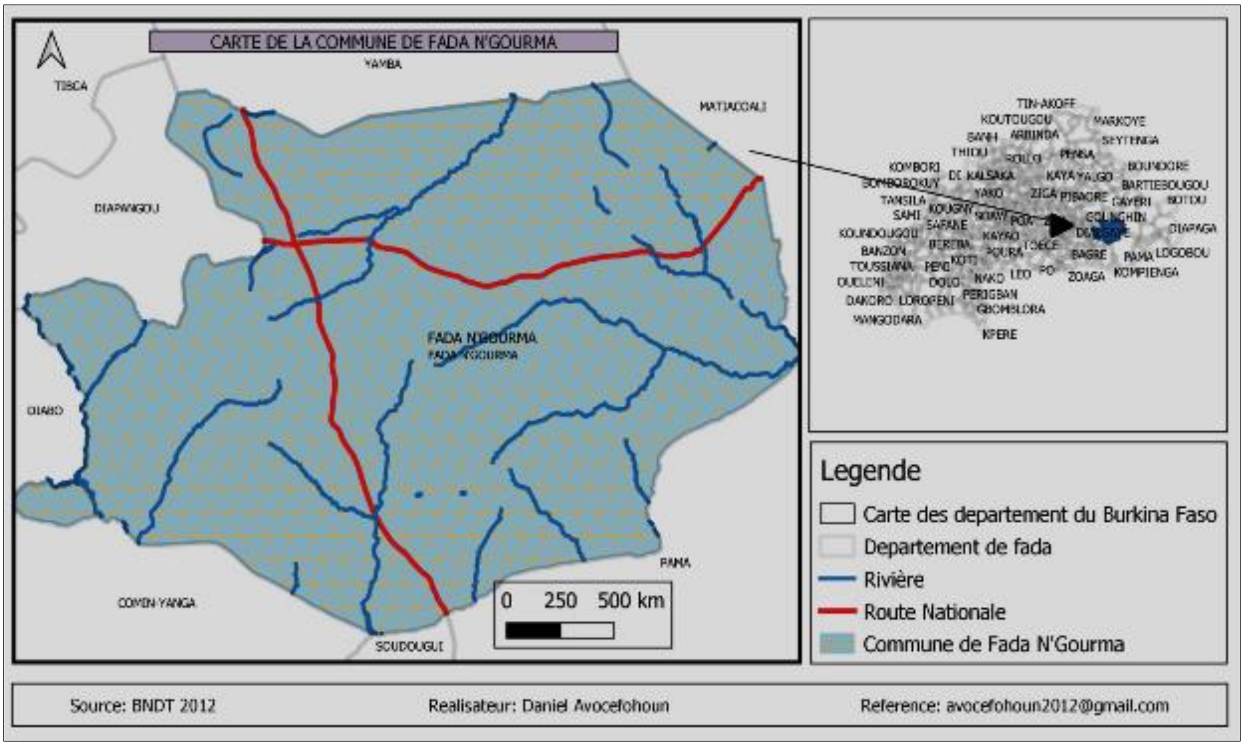

Figure 1 Map of study area location

2.2. Experimental set-up

The trial was conducted in a completely randomized Fisher block design, consisting of two blocks. The Bokashi treatment was tested in block 1 and the local liquid fertilizer treatment in block 2. Block 1 consisted of six (06) treatments, including the control, and four (04) replicates, while block 2 consisted of seven (07) treatments and four

(04) replicates. In block 2, seven (07) elementary plots correspond to the seven (07) treatments in each compartment and are separated by 1 m. Each elementary plot in block 2 has an area of 20.25 m^{-2} (4.5 m x 4.5 m). The individual plots were separated by a 1.5 m aisle. Each elementary plot in the two blocks has an area of 20.25 m^{-2} (4.5 m x 4.5 m) and is separated from each other by a distance of 1m. The two blocks were separated by a distance of 2 m (figure 2).

2.2.1. The different treatments compared in the two blocks are shown below

Block 1

- T0: Ploughing without fertilizing (control)
- T1: Ploughing + spreading of 6.2 t/ha of manure;
- T2: Ploughing + spreading of 6.2 t/ha du bokashi;
- T3: Ploughing + spreading of 3.1t/ha du bokashi;
- T4: Ploughing of 3.1t/ha of bokashi before Ploughing + 3.1t/ha of bokashi after Ploughing
- T5: Ploughing of 6.2 t/ha of bokashi before Ploughing + 6.2 t/ha du bokashi after Ploughing.

Block 2

- T0: Ploughing without fertilizing (control);
- T1: Ploughing + spreading of 3.1t/ha of Manure;
- T2: Ploughing + local liquid fertilizer (1500l/ha);
- T3: Ploughing + local liquid fertilizer (3000l/ha);
- T4: Ploughing + local liquid fertilizer (4500l/ha);
- T5: Ploughing of 3.1t/ha of bokashi before Ploughing + local liquid fertilizer (1500l/ha) + spreading of 0.1 t/ha of bokashi after Ploughing;
- T6: Spreading of 3.1t/ha of bokashi before Ploughing + local liquid fertilizer (3000l/ha) + 0.1 t/ha of bokashi before Ploughing.

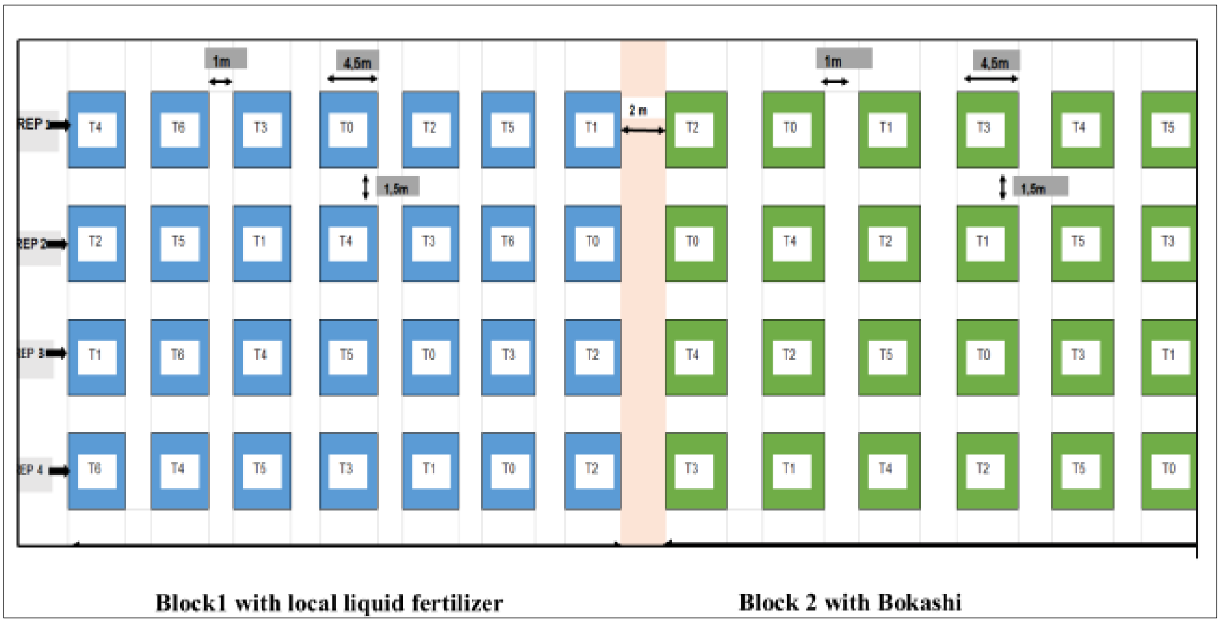

Figure 2 Experimental design

2.3. Experimental management

2.3.1. Plant material

The “Nassodo” variety, a local sorghum variety with a 70-day cycle, was used. It is white in color, with yields ranging from 2.5 to 4 t/ha. The seedlings were sown at a distance of 80 cm between rows and 40 cm between bunches. Three weeding operations were carried out to maintain the crops.

2.3.2. Fertilizer preparation and application

The bokashi used was produced on the experimental site in 15 days using the aerobic fermentation method with the following substrates: clay soil, cow dung, sorghum husk, maize bran, charcoal powder, ash, brown sugar and local brewer's yeast, and used at a rate of 30 t/ha.

Liquid fertilizer was also produced on site and was ready four (04) weeks following the aerobic fermentation method with the following ingredients: green leaves of piliostigma (*Piliostigma reticulatum*), green leaves of moringa (*Moringa oleifera*), cow dung, chicken droppings and excreta of small ruminants. In addition to these fertilizers, cow dung was used in some treatments. This manure was obtained from local livestock farmers. Harvesting was carried out manually on the 85th day of the month in each 1 m^{-2} yield square for each treatment. Yield squares were marked out in advance in the center of each elementary plot.

2.3.3. Data collection

- Plant emergence rate using the following formula: TLP (%) = NPP/NTP × 100 (where NPP = number of plants that emerged; NTP = total number of bunches of plants that emerged). Grain and straw yields
- The weights of grain (fresh and dry) and straw (fresh and dry) were assessed in 1m-square yield squares.

2.3.4. Soil macrofauna sampling

Soil macrofauna includes all soil invertebrates larger than 2 mm, i.e. those easily visible to the naked eye. The TSBF (Tropical Soil Biology and Fertility) method recommended by [13]and [14] was used to determine macrofauna. For each sampling point, a 30 cm-deep section of soil was excavated using a 25 cm square metal frame. Individuals visible to the naked eye were taken immediately and manually from each block of earth after excavation, and preserved in 70°C alcohol. The soil macrofauna inventory was carried out on the 75th day of the year on the median line of each elementary plot. It was carried out entirely in the morning, before 10 a.m., to avoid the descent of individuals into the depths due to the sun.

A total of 50 monoliths were extracted, including three from each elementary plot, but there were levels where nothing was found in the soil. Soil macrofauna were carefully collected and identified using identification keys [15, 16]. With the difficulties of identifying juvenile and larval stages, most groups were identified down to the genus level. Data on macrofauna were used to calculate density (average number of individuals.m^{-2}) and diversity. Diversity was assessed using the Shannon Weaver index (H'). This index takes into account the number of groups encountered (s). Its value was obtained using the following formula [17]

$$\mathbf{H'} = -\sum_{\mathbf{i=1}}^{\mathbf{s}} \mathbf{pi.\log_2(pi)}$$

- Pi = probability of encountering taxon i on a plot
- S = total sum of taxa encountered on the plot

This index is zero when there is only one taxon, and its value is maximum when all taxa have the same abundance [17].

2.4. Soil sampling and analysis

Soil samples were taken at a depth of 0-20 cm at five (05) points along the diagonals of the experimental field before fertilizer application. The soil and organic fertilizers parameters evaluated were as follows:

- pH: was evaluated as [18]
- Total nitrogen was assessed using the modified Kjeldahl method [19]
- Organic carbon was determined using the Walkley and Black method[20].
- Total phosphorus and available potassium were determined using the Bray 1 method[21];
- Cation Exchange Capacity (CEC) according to the analytical method of [22].
- Exchangeable bases and Cation Exchange Capacity (CEC) according to the analytical method of [22].

2.5. Statistical analysis

Analysis of variance (ANOVA) was performed using R software version 4.4.1. The Tukey test was used to check the homogeneity of variances, while the Shapiro-Wilk test was used to check normality. The Tukey test was used to compare means when the analysis of variance revealed significant differences between treatments, at the 5% probability threshold.

3. Results

3.1. Chemical characteristics of organic fertilizers

The results on the chemical characteristics of the fertilizers showed a higher water pH for Bokashi at 9.39, compared with 7.51 for liquid fertilizer. Total nitrogen and total phosphate were higher with Bokashi, at 0.04 and 0.42 g/kg respectively.

Table 1 Chemical characteristics of organic fertilizers (Bokashi and local liquid fertilizer)

Chemical parameters	Bokashi	Local liquid fertilizer
pH water	9.39	7.51
C-total (%)	2.93	-
M.O -total (%)	5.06	-
N-total (g/kg)	0.09	0.01
C/N	32.6	-
P-total (g/kg)	0.42	0.02
K-total (g/kg)	0.33	-
P-Bray (mg/kg)	36.9	-
Ca2+ (cmol.kg-1)	47.41	-
Mg2+ (cmol.kg-1)	11.36	-
K+ (cmol.kg-1)	7.42	-
Na+ (cmol.kg-1)	3.19	-
SBE (S) (cmol.kg-1)	69.35	-
CEC (cmol.kg-1)	7.05	-

Legend: pH eau: pH water; C-total: Total Carbon; M.O: Organic matter; N-total: Total nitrogen; P-total: Total phosphorus; K-total: Total potassium; P-Bray: Phosphore Bray; Ca: Calcium; Mg: Magnesium; K: Potassium ; Na: Sodium; SBE: sum of exchangeable bases; CEC: Cation exchange capacity.

3.2. Germination/emergence rate

The results showed that germination rates ranged from 83.33 to 95.75% in Block 1 and from 83.17 to 95.75% in Block 2. However, statistical analysis showed no significant difference between treatments in either Block 1 or Block 2.

Table 2 Germination/emergence rate

Block	Treatments	Germination/emergence rate (%)
I	T0	95,75a ±8,50
	T1	83,33a±19,25
	T2	95,75a ±8,50
	T3	91,50a±9,81
	T4	91,67a±16,67
	T5	95,75a±8,50
	P-value	0,711

	Significance	NS
II	T0	91,67a ±16,67
	T1	95,75a ±8,50
	T2	83,175a ±13,61
	T3	91,50a ±9,81
	T4	91,50a ±9,81
	T5	91,50a ±9,82
	T6	91,50a ±9,81
	P-value	0,849
	Significance	NS

NB : Les valeurs suivies de la même lettre, dans une même colonne, ne sont pas significativement différentes au seuil de 5% de probabilité. Legend: T0: No-input ploughing ; T1: Manure (6.2t/ha); T2: Bokashi (6.2t/ha); T3: Bokashi (3.1t/ha) ; T4 : Bokashi (3.1t/ha) before ploughing + Bokashi (3.1t/ha) after ploughing; T5: Bokashi (6.2 t/ha before ploughing ; 6.2t/ha after ploughing) ; T0: No-input ploughing T1 : Manure (3.1t/ha); T2 : local liquid fertilizer (1500l/ha/; T3: local liquid fertilizer (3000l/ha); T4: local liquid fertilizer (4500l/ha); T5: Bokashi (0.1 t/ha before ploughing +1500l/ha); T6: Bokashi (0.1 t/ha before ploughing + 3000l/ha)

3.3. Yields

3.3.1. Variation in yields and straw by treatments

Table 3 variation in grain and straw yields by treatment

Blocks	Treatments	Grain yield (kg/ha)	Straw yield (kg/ha)
I	T0	2157,6a ± 63,04	2625a ± 1652,02
	T1	2480,1ab ± 164,98	2875a ± 1750,00
	T2	2661,9b ± 321,50	3500a ± 2198,48
	T3	2474,7ab ± 204.85	2625a ± 1030,78
	T4	2520,0ab ± 270,39	3625a ± 2495,83
	T5	2448,6ab ± 164,73	2375a ± 1796,99
	P-value	0,038	0,909
	Significance	S	NS
II	T0	2190,0a ± 209,34	2750a ± 2020,73
	T1	2769,0a ± 488,27	5125a ± 3350,99
	T2	2469,0a ± 142,79	3125a ± 1652,02
	T3	2294,7a ± 187,09	2000a ± 1354,01
	T4	2547,0a ± 82,78	3125a ± 478,71
	T5	2487,0a ± 310,67	3500a ± 1779,51
	T6	2724,0a ± 319,00	3750a ± 957,43
	P-value	0.076	0,404
	Significance	NS	NS

Values followed by the same letter in the same column are not significantly different at the 5% probability level; Legend : T0: No-input ploughing ; T1: Manure (6.2t/ha); T2: Bokashi (6.2t/ha); T3 : Bokashi (3.1t/ha) ; T4 : Bokashi (3.1t/ha) before ploughing + Bokashi (3.1t/ha) after ploughing; T5 : Bokashi (6.2 t/ha before ploughing ; 6.2t/ha after ploughing) ; T0 : No-input ploughing T1 : Manure (3.1t/ha); T2: local liquid fertilizer (1500l/ha/; T3: local liquid fertilizer (3000l/ha); T4: local liquid fertilizer (4500l/ha); T5: Bokashi (0.1 t/ha before ploughing +1500l/ha); T6 : Bokashi (0.1 t/ha before ploughing + local liquid fertilizer 3000l/ha); NS: not significant; JAS: day after sowing.

The results showed that treatment T0 had the lowest grain yields in both blocks. The highest yields were found in treatments T2 with 2.6t.ha-1 in block 1 and 2.76 t.ha-1 in treatment T6 in block 2. Straw yields ranged from 2,000 to 5,125 t.ha-1. Statistical analysis was only significant in block 1 ($p<0.04$).

The results of the analysis showed that in block1, the manure treatment (T1) presented the highest value with 24 individuals.m-2 followed by the T2 treatment with a density of 21 individuals.m-2. The no-tillage treatment (T0) gave the lowest density of 11 individuals.m-2. As for the diversity index, the highest value was observed with treatment T1 (1.48). In block 2, densities varied from 24 to 33 individuals.m^{-2}. However, it should be noted that overall, the statistical analysis did not vary significantly between treatments.

Table 4 Variation in total density and macrofaunal diversity index as a function of treatments

Blocks	Treatment	Total density (individuals/m^2)	Diversity index
I	T0	11	1.08
	T1	24	1.48
	T2	21	1.08
	P-value	0.355	0.126
	Signification	NS	NS
II	T0	24	1.06
	T4	33	1.18
	T6	25	1.35
	P-value	0.564	0.482
	Signification	NS	NS

Legend: T0: No-input ploughing; T1: Manure (6.2t/ha); T2: Bokashi (6.2t/ha); T0: No-input ploughing; T4: local liquid fertilizer (4500l/ha); T6: Bokashi (0.1 t/ha before ploughing + 3000l/ha)

4. Discussion

4.1.1. Chemical characteristics of organic fertilizers

The chemical characteristics of organic fertilizers show a significant content of organic matter, total nitrogen, total phosphorus, total potassium and a largely alkaline water pH in bokashi organic fertilizer compared with liquid fertilizer, which has a low content of these nutrients. Bokashi has a C/N ratio of 32.6 and a basic pH. These two parameters are crucial to the maturity of formulated composts [23]. Indeed, mature composts have a pH of between 7 and 9 and a C/N ratio of between 10 and 20, which explains the relatively high content of basic elements (Ca^{2+}, Mg^{2+}, K^+ and Na^+) in this compost, necessary for good plant development. These results are in line with international standards, which set the following fertilizing element contents for organic soil improvers described as very rich: total organic matter > 5%, total phosphorus > 0.3%, total nitrogen > 0.25%, a C/N ratio of 20 and a neutral pH [18]. Bokashi is therefore stable. Composts with a C/N below 10 are well mineralized and low in humus compounds. This could be explained by the important role played by bokashi's constituent elements. Bokashi is made up of sorghum husks, corn bran, rice husks, cow dung, poultry droppings, clay, ash, charcoal powder, brown sugar and yeast. These components provide the soil and crops with the nutrients they need to grow. Some authors attribute to Bokashi a rapid efficiency comparable to mineral fertilizers, while improving the biological quality of the soil [24].

4.1.2. Effects of organo-mineral fertilizers on sorghum yield parameters and sorghum yields

Grain and straw yields from plots treated with bokashi and manure were significantly higher than those from the T0 control treatment. These soils are better supplied with organic matter and fertilizing elements such as nitrogen, phosphorus and potassium from the decomposition of composted plant biomass. By loosening the soil, organic matter enables sorghum to root well. This, in turn, ensures good water and mineral supply to the sorghum plants. All these conditions could explain the differences in grain and straw yields in treatments T1 (manure) and T2 (bokashi) compared with the others. These results are in line with those obtained by[25] who showed that potassium (K) stimulates the constitution of nutrient reserves; nitrogen is involved in the main yield-determining processes, and phosphorus could accelerate seed setting and seed maturation. Moreover, this result can be explained by the important role played by bokashi and manure in sorghum seed formation. Nitrogen and nitrogen nutrition show that nitrogen is probably the most important factor in increasing crop yields [26]. Organic matter also improves soil water retention capacity. This factor improves dry matter production, which translates into plants with good vigour that are more resistant to climatic hazards, resulting in higher yields [27, 28]. Our results are similar to those of [28], who showed that compost application, even at low doses, has a positive effect on cereal crop yields. Our results corroborate those of [9] who observed that a combination of organic manure and mineral fertilizer increases cereal crop yields in Sahelian zones, due to a synergy between rapid nutrient inputs and prolonged release. [2] note that the continuous application of organic fertilizers improves yields over the long term by maintaining organic matter and promoting microbial activity. [11] confirm the effectiveness of Bokashi in increasing crop yields under similar climatic conditions, thanks to its high content of assimilable nutrients. The development of a crop's above-ground biomass is all the more important the more fertile the soil is in fertilizing elements such as nitrogen, phosphorus and potassium. These elements are contained in manure and bokashi. They promote sorghum growth and vegetative development. Manure is richer in nutrients immediately available to plants [29]. Nitrogen is par excellence the element that accelerates plant biomass production. It can be said that organic fertilization promotes the production of dry biomass. This result could be explained by the soil nutrient content of bokashi and manure, which contributed to the growth and vegetative development of sorghum. It could also be explained by the high availability of nutrients. Indeed, according to [30], the development of a crop's above-ground biomass is all the more important if the soil itself is rich in fertilizing elements.

However, it should be noted that sorghum grain yields obtained with treatments receiving organo-mineral fertilizers are significantly higher than those observed in the farming environment, which varied between 1,500 kg/ha and 2,500 kg/ha over the period 2005-2010[31]. This could be explained by the beneficial effects of organo-mineral fertilization on crops, and the improvement in soil chemical parameters observed with manure and bokashi at average doses (6.2 t/ha). Plants take advantage of the mineral elements provided by the amendments to develop[32]. Our results corroborate those of [33], who showed that improved sorghum and millet varieties can give higher yields than local varieties if they benefit from good production conditions (fertility, low competition with weeds, rainfall, etc.). They go on to say that local varieties are hardier and do not require as much care as improved or imported varieties. Our results are also in line with those of [34, 35], who concluded from his work that improved sorghum varieties are more productive than local varieties.

With regard to local liquid fertilizer, grain yields were also higher in the treatments with this fertilizer than in the control without it. However, statistical analysis did not reveal any significant differences.

4.1.3. Variation in total macrofaunal density and diversity index as following the treatments

The results indicate that the treatments did not significantly improve the number and diversity of soil macrofauna. These results could be explained by the climatic conditions under which the macrofauna were studied. Indeed, when the macrofauna were sampled, the soil was completely dry, and this could be the factor explaining the lack of difference observed between treatments. According to [36], water is an essential factor for soil pedofauna, and both excess and deficiency are detrimental. These results corroborate those of [37], who also found no significant difference between different agroecological practices on macrofauna in ferric lixisols in the Sudan-Sahelian zone of Burkina Faso. According to these authors, soil macrofauna is not only influenced by agricultural practices, but also by other factors such as the quality and quantity of organic resources. However, authors such as [38] and [30] have found in their respective studies that the application of organic manure significantly improves soil macrofauna.

5. Conclusion

The aim of this study was to evaluate the effectiveness of biofertilizers (bokashi and local organic liquid fertilizer) on productivity in Burkina Faso. The results of this study showed that the behavior of sorghum after application of various biofertilizers produced was better than the control treatment without fertilizer. High doses of bokashi or liquid organic fertilizer gave significant results on sorghum yields. Treatment T2 (5 t/ha of bokashi) recorded biomass yields of 5637.50 t/ha and grain yields of 3204.45 t/ha, while treatment T4 (4500 l/ha) obtained biomass yields of 5612.50 t/ha and grain yields of 3361.13 t/ha. This confirms the advantages of these natural fertilizers in improving soil properties and making nutrients available in the soil, while reducing the risk of degradation. This study shows that the use of biofertilizers is decisive for cereal production in general and sorghum production in particular. In view of the results obtained, liquid and solid biofertilizers could be an interesting alternative for managing soil fertility and achieving food self-sufficiency. However, further study is required to consolidate the results obtained.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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