Compost, a natural fertilizer to improve pearl millet [Pennisetum glaucum (L.) R. br.] growth and its productivity in the Sahel (south-eastern Niger): an experiment to convince small producers to manage their soil sustainably

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ABSTRACT

In the Sahel, millet (*Pennisetum glaucum* L.) is one of the main cereals cultivated as rain-fed crops, predominantly by vulnerable small producers, on poor soils leading to increasingly low growth and production. The aim of this work was to increase millet production by using organic manure (compost) at low cost (accessible to all) and respectful of the environment. The methodology used was participatory (with producers) and consisted of monitoring the growth and yield parameters of two varieties (local and improved) of millet by applying three doses of compost: low dose (1 tha^{-1}), medium dose (3 tha^{-1}) and high dose (5 tha^{-1}) with a control (without compost). The results showed that millet achieves most of its growth in height before the 71st day after sowing. The high dose of compost increased the height of the millet plants by more than 22 cm and the number of tillers by more than 17% compared to the control. The variety of millet did not directly affect plant height and number of tillers. The high dose of compost increased the yield by more than 44% and the dry matter by more than 37% compared to the control. The yield of the improved millet variety increased by more than 32% compared to the local variety. The local variety had an increase in dry matter of more than 11% compared to the improved variety. The study helped convince several producers to accept the use of compost. Its large-scale extension, in producers' fields, could convince those who are reluctant to adopt innovation.

Keywords: Cereals, Variety, Soil Fertility, Organic -Manure, Small Producers.

INTRODUCTION

In the Sahel, millet is one of the most important cereal crops because of its production capacity even under the most difficult conditions (Bisht et al., 2019; Hanna et al., 2004). It can be produced where many other cereals cannot (Varshney et al., 2017).

According to Bisht et al. (2019) and Yadav et al. (2024), millet is mainly farmed in arid areas, which are marginal production environments with inherent low soil fertility and low water holding capacity. This is why its farming is expanded in semi-arid regions of the world, mainly in West Africa (Bisht et al., 2019; Dussert et al., 2015; Hamadou et al., 2017). Despite its importance, “millet is a largely neglected and underutilized crop” (Bisht et al., 2019).

In Niger, millet is cultivated as an extensive crop under difficult conditions of soil and climate but it’s one of the important cereals produced in rain-fed farming (Leblois et al, 2014; Abdoulaye and Sanders, 2006). It is cultivated on more than 65% of the sown area and represents 75% of the total cereal production of the country which ranks second among producing countries in Africa after

Nigeria (Kadri et al., 2019). However, many constraints hinder its farming. The most common of which are climatic deterioration and decline in fertility of cultivated land practically without consistent and regular inputs of fertilizers or even organic matter (Pale et al., 2021).

Moreover, millet is mainly cultivated by vulnerable small producers powerless to the effects of climate change and on traditional family farms, entirely cultivated under rain-fed conditions with few inputs (Marteau et al., 2011). They hardly use mineral fertilizer for these crops because of its high cost (Sissoko and Le Bailly, 2019). These producers systematically collect crop residues, in particular millet stalks, which are used for many purposes (storage for feeding livestock, making fences for yards, sheds, granaries, etc.) which leaves soils without any protection. This situation has led to the decline in soil fertility which is a major constraint for sustainable agriculture in smallholder farming systems (Bedada et al., 2014; Agegnehu et al., 2016). In this circumstance, the use of compost is an alternative because several studies have shown its role in restoring the fertility of agricultural land and increasing crop production (Agegnehu et al., 2016; Pérez-Piqueres et al., 2006; Rivero et al., 2004). Indeed, Sawadogo et al. (2008) reported that compost increases parameters such as water pH and KCl, total organic carbon, total nitrogen, and phosphorus available in the soil in Burkina. However, Ouédraogo et al. (2001) did not observe any significant difference in the organic matter content of the soil between the treatments with compost and without compost, but they reported that the application of compost increased the capacity of soil cation exchange (CEC) from 4 to 6 cmol kg^{-1}, the soil pH was also increased and the crop yield either tripled or increased by 45% on the plots that received the compost. For Lakhdara et al. (2009) the use of compost is a low-cost technique to improve the physical, chemical, and biochemical properties of soils. According to Termorshuizen et al. (2004), compost is one of the most stable sources of organic matter. It is based on the low yields of millet in the Nigerian Sahel and on all the advantages of compost that the present research and development work was carried out to convince small producers to use organic matter to improve pearl millet growth and increase its productivity.

MATERIALS AND METHODS

Site description

The experiment was carried out in Niger, located in the heart of the Sahel, on an experimental site in a village (Adebour) located between 13 ° 19 'South Latitude and 11 ° 52' East Longitude (Figure 1). The climate in the study area is Sahelian with a single rainy season period. The latter usually runs from June to September. The average annual precipitation, calculated over 67 year (between 1940 and 2007) is 370.4 ± 108.9 mm of rain per year (Ozer et al., 2007). The soil of the experimental site, analyzed at the start of the experiment, in the soil laboratory of the National Agronomic Research Institute of Niger (INRAN), has a sandy-loamy texture and physicochemical characteristics included in Table 1. This soil corresponds to lowland soils deemed to be more fertile than sandy soils on which millet cultivation is mainly carried out (Ambouta et al., 2018; Sawadogo et al., 2008).

Experimental design

The experiments were carried out with the support of ten pilot farmers (5 men and 5 women), chosen from among the population by their peers. The experimental device used was a randomized block factorial device with six repetitions and eight treatments (2 varieties x 4 doses of compost). The size of the experimental plot was 12 m^2 (4m x 3m) and the millet was sown with a spacing of 1m both between the pockets and between the rows. The distance between two plots of the same block was 1 m and that between two blocks was 2 m. The experiment was carried out during rainy season periods, in 2020 and 2021. The treatments applied combined four doses of compost: C0 = without compost (control), CL = 1tha^{-1} (low dose), CM = 3tha^{-1} (medium dose) and CH = 5tha^{-1} (high dose) and two varieties of millet, the local millet variety (ML) and the improved millet variety (MI). The treatments were: T1. OCLM: without compost x local millet; T2. OCIM: without compost x improved millet; T3. LCLM: low dose compost x local millet; T4. LCIM: low dose x improved millet; T5. MCLM: medium dose x local millet; T6. MCIM: medium dose x improved millet; T7. HCLM: high dose x local millet and T8. HCIM: high dose x improved millet (Figure 2). These doses are abnormally low compared to those commonly used (5 to 10tha^{1}) (Sawadogo et al., 2008; Ouédraogo et al., 2001) in the Sahel. The choice of these doses was made in taking the opinions of producers who underlined the important aspect of crop residues for their many uses (storage for feeding livestock, making fences for yards, sheds, granaries, etc.) and the availability of materials to be composted.

Compost production

The compost used was produced from crop residues (mainly millet stalks), organic manure, household refuse free of nondegradable elements and ash. These elements were composted in pits 3m x 2m and 1m deep installed near a water basin fed by a borehole on the experimental site. Thus, the maintenance of the required humidity in the decomposing material was facilitated. Composting began two months before the start of the 2020 rainy season which started on July 24, 2020. Part of the compost was dried in a shade, for 2 days and then kept in a bag in a dry place, out of direct sunlight for use during the 2021 season, which started on July 09, 2021. The physicochemical characteristics of the compost produced and analyzed at the soil laboratory of International Crops Research Institute for the Semi-arid Tropics of Niger (ICRISAT), are recorded in Table 2.

Crop and soil management

The installation and agricultural operations (soil preparation, sowing, stripping, weeding, incorporation of compost into the soil, monitoring of measurements, harvesting, shelling, weighing, etc.) were carried out with the farmers under the supervision of two technicians (an extension technician and an agricultural engineer intern). The compost was spread over the plots and lightly buried before sowing. The plant material was made up of two varieties of millet, one local, called "*Goudis*", loved by the producers for its precocity and its hardiness and an improved one, "*HKP"* (*Haïnikiré*) used for its precocity and hardiness because all its characteristics are efficient and adapted to the study area. The choice of these varieties was motivated by the wish of the program to popularize the improved variety and the wish of the farmers to keep their local variety which they deem efficient. The two varieties of millet were sown according to the plan of the design, on July 24, 2020, for the 2020 season and on July 9, 2021, for the 2021 season. During the experiments, the plots were weeded twice, and supplemental irrigation was brought during the few dry period (one week without rain). The crops were harvested 12 weeks after sowing.

Data collection

During the experiment, the following growth parameters were monitored: the variation in the height of the plants and the variation in the number of tillers (every 10 days from the 31st day after sowing to the 81st day after sowing), the variation in number of leaves per stem and variation in stem diameter (on the 31st, 41st and 51st days after sowing). At harvest (end of the experiment), the length and diameter of the cobs were measured. Data on millet dry matter and yield were obtained by sun drying and weighing. All its data was carefully verified using Excel software. Statistical processing (descriptive analyzes and analysis of variance (ANOVA)) was carried out with SPSS version 20. The comparison of means was performed by Duncan's test. The different sources of variation considered were, day after sowing (DAS), year (YR), compost dose (DC) and millet variety (VM).

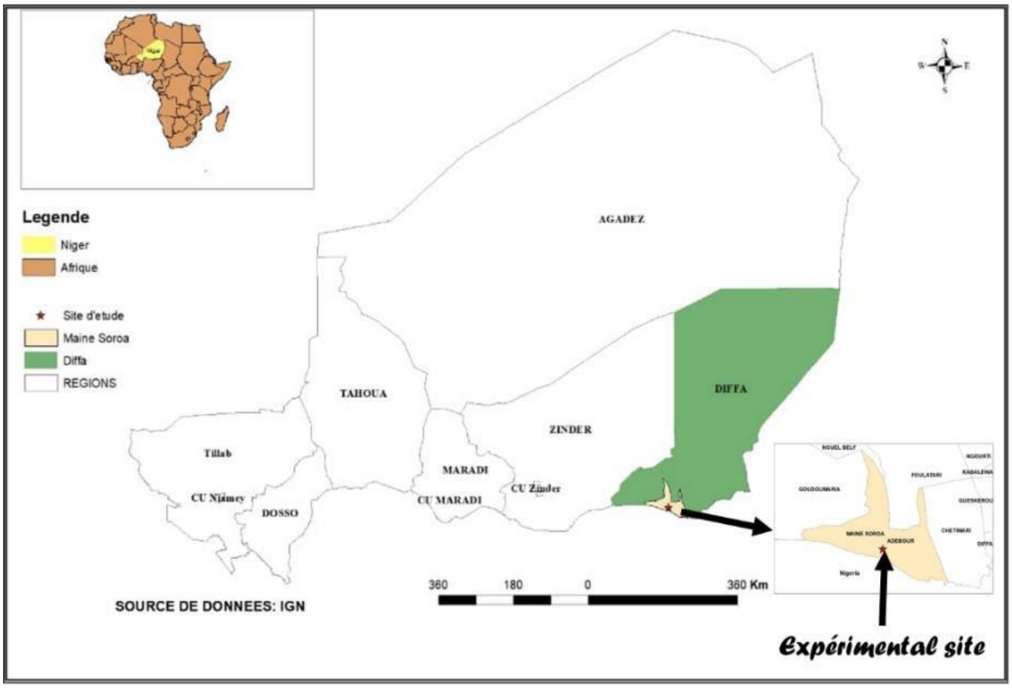

Figure 1: location of the experimental site.

Table 1: physicochemical characteristics of the soil at the experimental site.

Physicochemical parameter	Value
Water Potential of hydrogen pH (1:2,5)	7,95
Electrical conductivity (EC) (m^3/cm)	0,07
Calcium ion Ca^{2+} (Méq/100g)	11,10
Magnesium ion Mg^{2+} (Méq /100g)	2,19
Sodium ion Na^{+} (Méq /100g)	0,22
Potassium ion K^{+} (Méq /100g)	0,68
Cation exchange capacity CEC (Méq /100g)	14,19
Assimilable phosphorus P (ppm)	0,69
Carbon C (%)	0,23

Organic matter MO (%)	1,26
Nitrogen N (%)	0,06
Carbon to nitrogen ratio C/N (%)	2,33

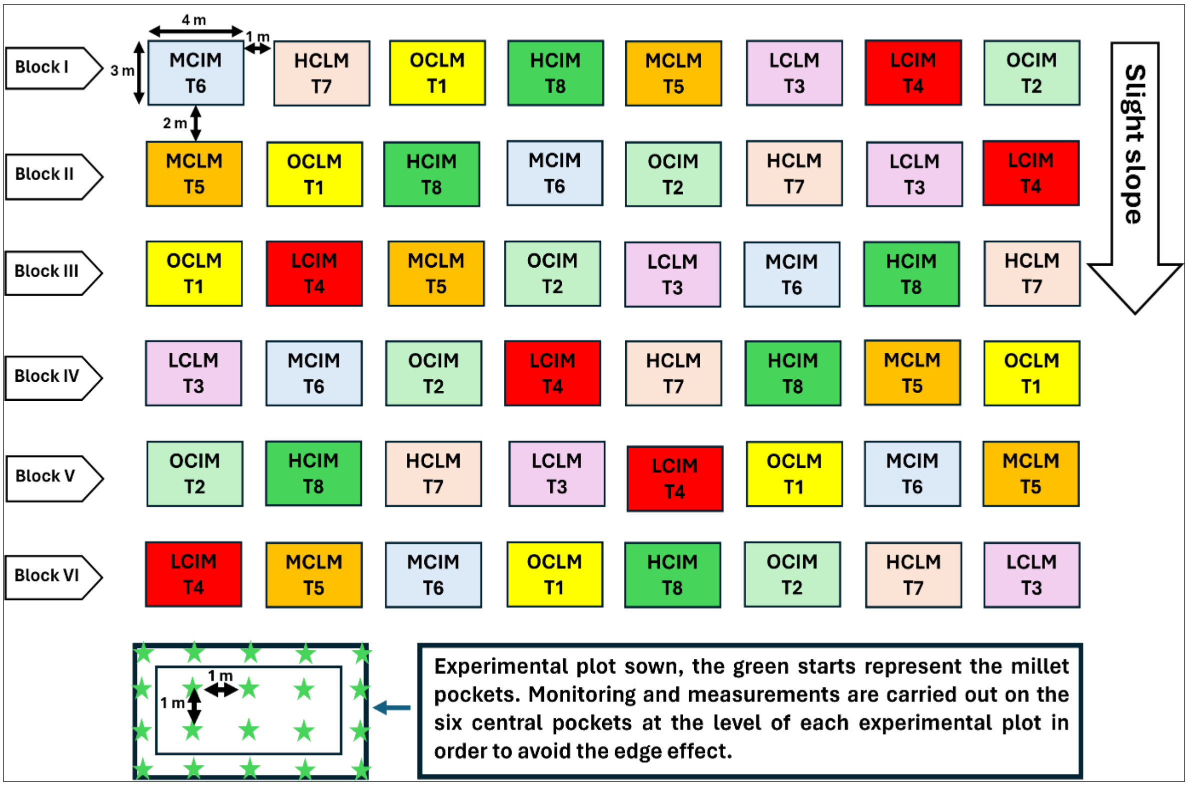

Figure 2: Experimental plan.

Table 2: physicochemical characteristics of the compost produced.

Physicochemical parameter	Value
Water Potential of hydrogen pH (1:2,5)	8,21
Total Potassium K (%)	0,46
Total Phosphorus P (%)	0,18
organic Carbon C (%)	10,2
Total Nitrogen N (%)	0,78
Carbon to nitrogen ratio C/N (%)	12,98

RESULTS

Effects of compost and millet variety on millet growth

Effect on millet plant height

Table 3 presents the results of the analysis of variance, having a significant effect ($p < 0.05$) on the parameters of millet growth (height of the millet plant, number of tillers, number of leaves per stem, diameter of millet stems and length of millet cobs). The parameter "diameter of millet cobs" is not influenced by any of the sources of variation. All the sources of variation (year, doses of compost and variety of millet) combined, two main phases are observed in the height growth of the millet plant as a function of the day after sowing: the “Continuous growth” phase and "Stable growth" phase (Figure 3.A).

Depending on the compost dose, the height growth curve of the millet plant with the high dose of compost differed from the three other height growth curves of the millet plant with respectively, without compost, with the low dose of compost and with the medium dose of compost (Figure 3.B). The last three curves are essentially the same. Depending on the year, the height growth curve in 2021 is slightly higher than that of 2020 (Figure 3.C).

The results of the variance analysis on the “plant height” parameter and the results of comparison of means per day after sowing (Figure 4.A) show that the average height of the millet plant increased exponentially from the first measure (31 DAS) to the fifth measure (71 DAS). In the last two measurements (71st and 81st DAS), the height remained statically the same. The height of millet plants increased an average of 151,56 cm from the first to the last measurement, most of which (92,78% increase) between occurred the first and the fourth measurement. From the latter, the height growth became less. Indeed, the change in height was respectively 30.24% from the 31st DAS to the 41st DAS, 42.61% from the 41st DAS to the 51st DAS, 19.83% from the 51st DAS to the 61st DAS and 7, 26% from the 61st DAS to the 71st DAS.

The result of the variance analysis carried out on the “plant height” parameter and the results of the comparison of averages per year (Figure 4.B) indicated that the average height of the millet plant in 2021 was statically higher than that of the millet plant in 2020. The average height of millet plants in 2020 which is 153.70 ± 83.75 cm increased to 161.83 ± 81.46 cm in 2021, an increase of about 8 cm in height.

The results of the variance analysis on the “plant height” parameter and the results of the comparison of means per dose of compost (Figure 4.C) showed that the compost had an effect on the height growth of the millet plant; the height with the high dose of compost ($5tha^{1}$) was much higher than that of three other doses of compost (compost free, low dose ($1tha^{-1}$) and medium dose ($3tha^{-1}$)). A low average height was obtained with the control (compost free). The average height with the low dose of compost was both statistically identical to the average heights with the control (compost free) and with the medium dose of compost. The millet varieties used did not have any effect on the height growth of the millet plant. However, the interaction between the dose of compost and the variety had a significant effect on the height growth of the millet plant (Figure 4.D). It emerges from this interaction that with the control and the low dose, it was the local variety which had an average height statistically higher than the improved variety. The opposite effect occurred with the medium dose and the high dose.

Effects on the number of tillers

The result of variance analysis on the parameter, “number of tillers” and the results of comparison of means (Figure 5.A) made it possible to understand that the average number of tillers was statically different for all the DAS, except for that of the 61st DAS which is statically identical to that of the 71st DAS. The highest average numbers of tillers (10.01 ± 4.83 and 10.07 ± 4.91) were respectively obtained at the 61st DAS and 71st DAS and the lowest average number of tillers (4.94 ± 2.42) was obtained at the 31st DAS.

The result of the variance analysis on the parameter "number of tillers" and the results of comparison of means per year (Figure 5.B) showed that the number of tillers produced in 2021 is statically higher to that produced in 2020. In fact, the average number of tillers, 7,26 ± 4,42 in 2020 increased to 8,84 ± 4,30 in 2021.

The result of the variance analysis on the parameter "number of tillers" and the results of comparison of the means per the compost dose (Figure 5.C) showed that it was with the high dose that the millet plant produces the high number of tillers, and a low number of tillers was produced with the control. The medium dose and the low dose produced the same number of tillers.

The interaction between the dose of compost and the year showed that whatever the dose, the number of tillers was always higher in 2021 than in 2020. Also, the interaction between the dose of compost and the variety of millet (Figure 5.E) showed that the low dose and the control allow the local variety of millet to produce a greater number of tillers than the improved variety of millet. The improved variety of millet produced more tillers than the local variety of millet with the high dose and the medium dose. ***Effect on the number of leaves***

The number of leaves produced was not influenced by the dose of compost and the variety of millet. However it was influenced by the DAS and on the three measurements, it could be seen that the number of leaves increased with time (Figure 6). The highest number of leaves (9,25 ± 1,37) was obtained at the 51st DAS and the lowest number of leaves (5,61 ± 1,03) at the 31st DAS. Between these two extreme measures, the number of leaves almost doubled.

Effect on the diameter of millet stems

The diameter of millet stems was influenced by the DAS, year, compost dose and millet variety. It increased with time (Figure 7.A) of the three measurements taken, it appears that the largest diameter (4,80 ± 0,73 cm) was obtained at the third measurement and the smallest (3,15 ± 0,56 cm) at the first measure. As a function of the year (Figure 7.B), the largest diameter (4,06 ± 0,98 cm) was obtained in 2021. In 2020 it was 3,67 ± 0,71 cm. The dose of compost allowed the largest diameter of the stem to be obtained with the medium dose and the high dose (Figure 7.C). The smallest diameter was obtained with the control. The diameter obtained with the low dose is comparable both to that obtained with the high and medium doses and with the control. As for the variety, it was the improved variety of millet that obtained the larger diameter than the local variety of millet (Figure 7.D).

Effect on millet cob length

The length of millet cobs was influenced by the dose of compost and the variety of millet. The longest cob (53,83 ±
16,10 cm) was obtained with the high dose and the shortest (36,42 ± 10,20 cm) with the control (Figure 8.A). The length of the cob with the medium dose was both identical to that with the low dose and the control. As for the millet variety, it was the improved variety that gives the longer cob (52,71 ± 11,92 cm) than the local variety (Figure 8.B).

Effects of compost and millet variety on millet yield

Table 4 presents the results of the variance analysis, having a significant effect ($p < 0.05$) on the millet yield parameters (yield and dry matter). ***Effects on grain yield***

The result of the variance analysis and those of the comparison of means (Figure 9.A) showed that the high and medium doses of the compost made it possible to increase the production of millet, all varieties combined. The yield obtained with the low dose did not differ from the yield obtained with the control. Moreover, the highest grain yield was obtained with the high dose of compost. The variety of millet influenced grain yield and the higher production was obtained with the improved variety of millet than the local variety of millet (Figure 9.B).

Effect on dry matter production

Millet dry matter production was influenced by the dose of compost (Figure 10.A), the variety of millet (Figure 10.B) and the interaction between the dose of compost and the variety of millet (Figure 10.C). The analysis of Figure 8A shows that the high dose of compost made was possible to obtain the highest dry matter yield. The medium dose came second. The low dose and the control had the lowest dry matter yield. Also, analysis of Figure 10.B shows that it was the local variety of millet that gave statically greater dry matter than the improved variety. Finally, analysis of Figure 10.C indicates that with the medium dose, the two varieties of millet had statistically the same dry matter production.

Table 3: Results of analysis of variance having a significant effect ($p < 0.05$) on the parameters of millet growth (height of the millet plant, number of tillers, number of leaves per stem, diameter of millet stems and length of millet cobs).

Parameters	**Sources of variation**	**Degree of freedom**	**Medium square**	**F test**	**Probability**
Height of the millet plant	DAS	5	2211910,61	645,64	<0,001**
	YR	1	54155,79	15,81	<0,001**
	DC	3	79084,89	23,08	<0,001**
	DC * VM	3	40285,95	11,76	<0,001**
Number of tillers	DAS	5	1268,893	81,726	<0,001**
	YR	1	2104,19	142,69	<0,001**
	DC	3	285,28	19,35	<0,001**
	YR * DC	3	72,03	4,88	<0,001**
	DC * VM	3	144,972	9,337	<0,001**
Number of leaves per stem	DAS	2	159,061	93,752	<0,001**
Diameter of millet stems	DAS	2	11,767	45,171	<0,001**
	YR	1	10,08	27,71	<0,001**
	DC	3	1,67	4,60	0,004*
	VM	1	18,24	50,16	<0,001**
Length of millet cobs	DC	3	1230,34	13,74	<0,001**
	VM	1	5969,26	66,65	<0,001**

DAS: day after sowing, DC: dose of compost, VM: variety of millet, *: significant, **: highly significant.

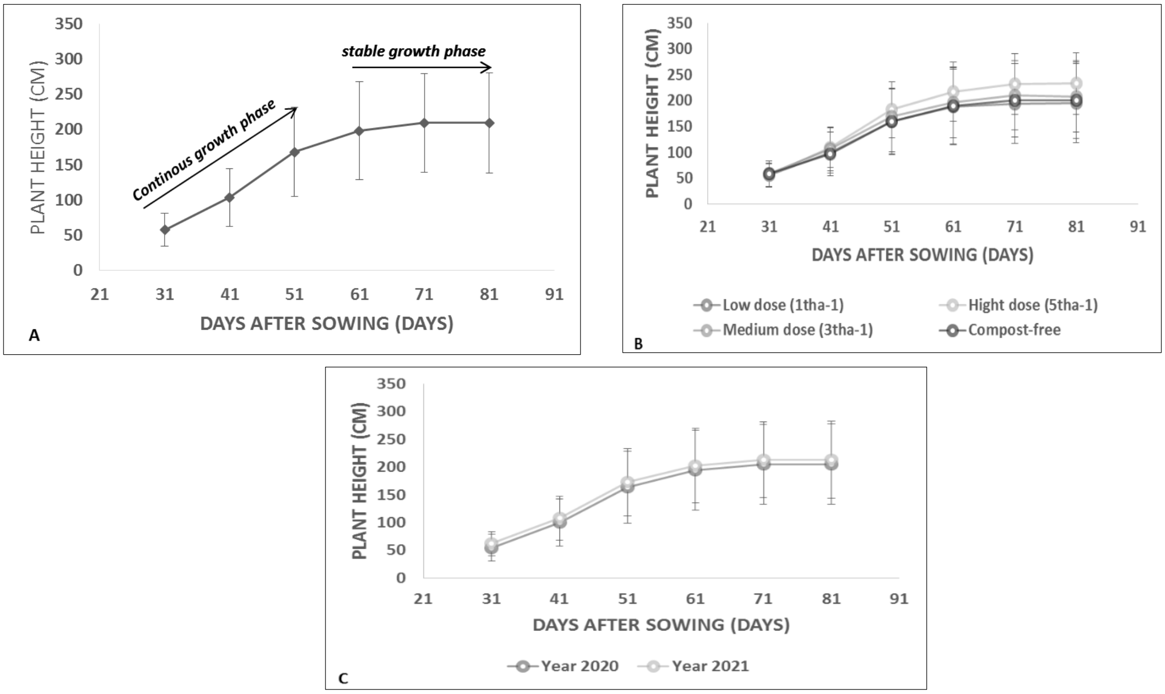

Figure 3: Evolution of the height of the millet plant as a function of days after sowing. A) Different height growth phases, B) Height depending on the dose of compost, C) Average height depending on the year.

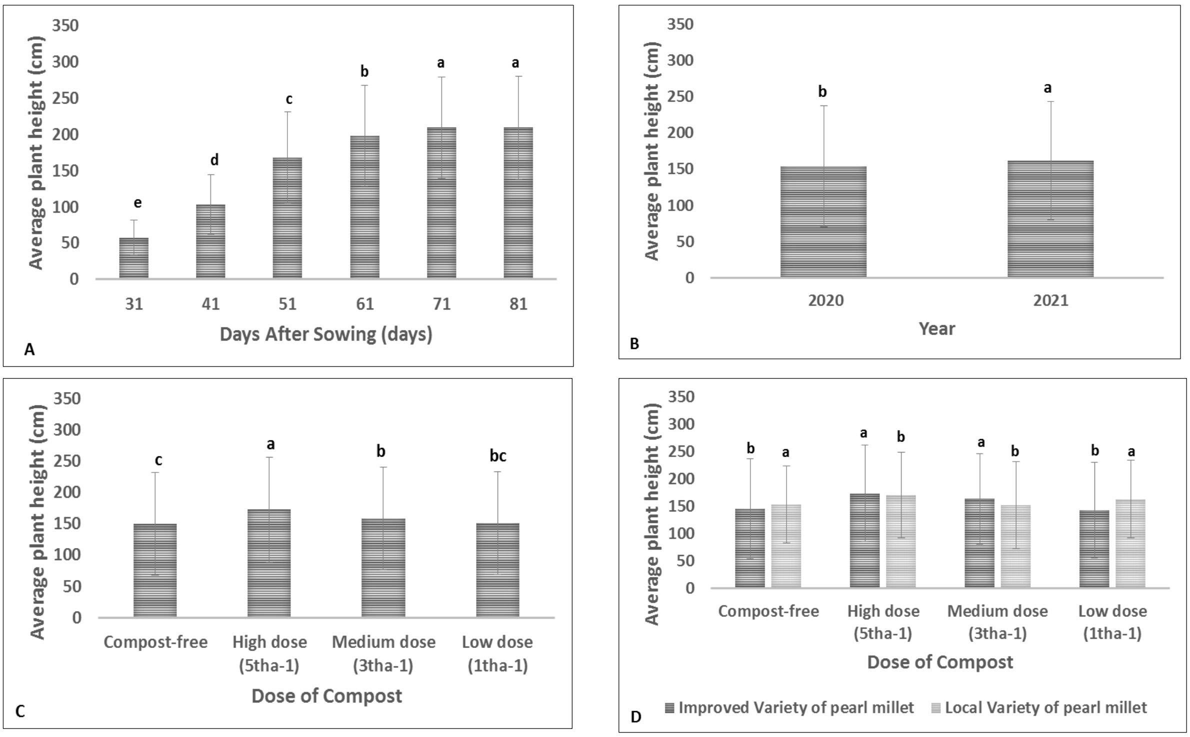

Figure 4: Average height of the millet plant A) as a function of DAS, B) as a function of the year, C) as a function of the compost dose, D) as a function of the interaction between the compost dose and variety of millet

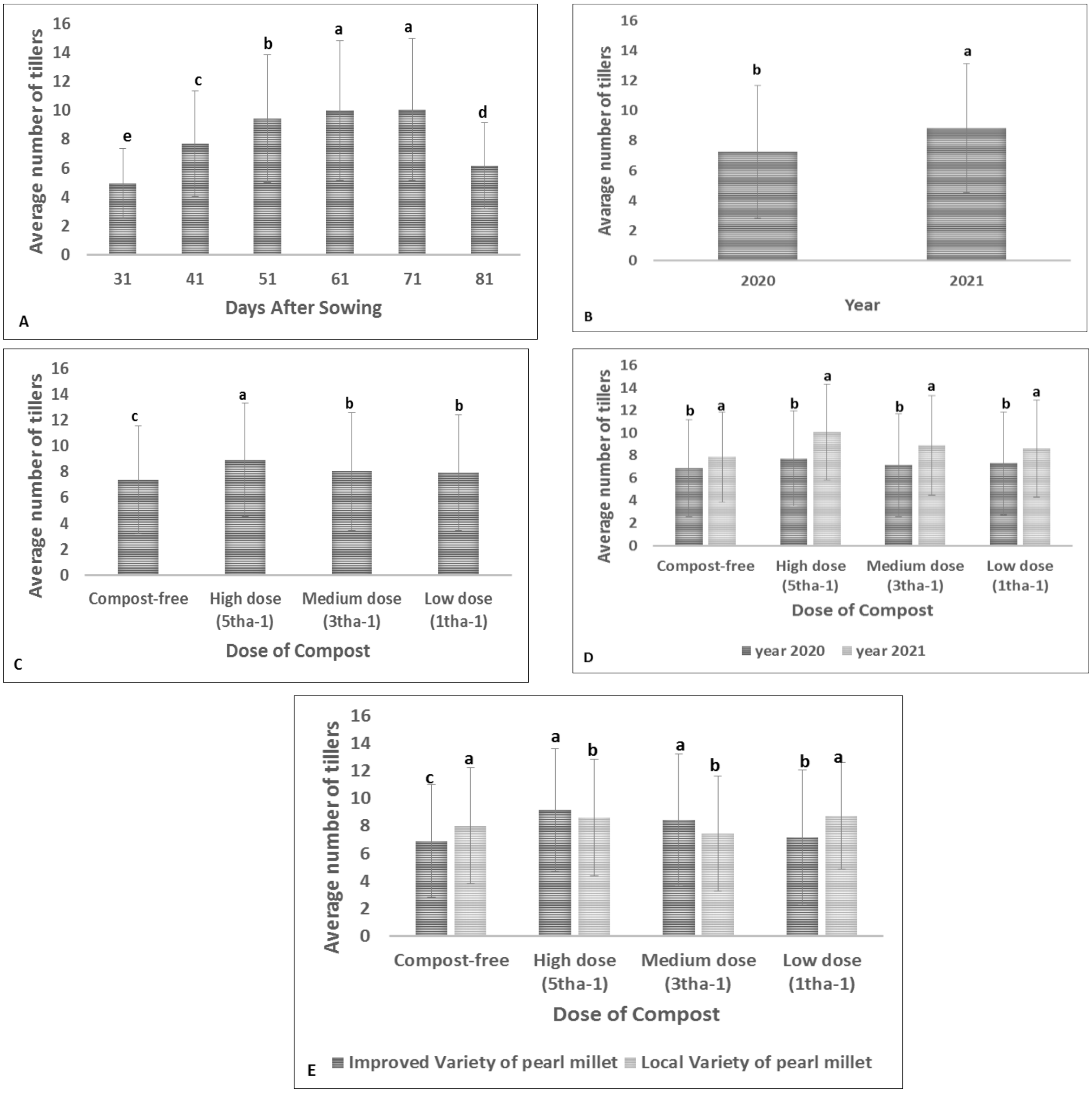

Figure 5: Average number of tillers: A) as a function of DAS, B) as a function of year, C) as a function of compost dose, D) as a function of the interaction between year and compost dose, E) as a function of the interaction between the dose of compost and the variety of millet.

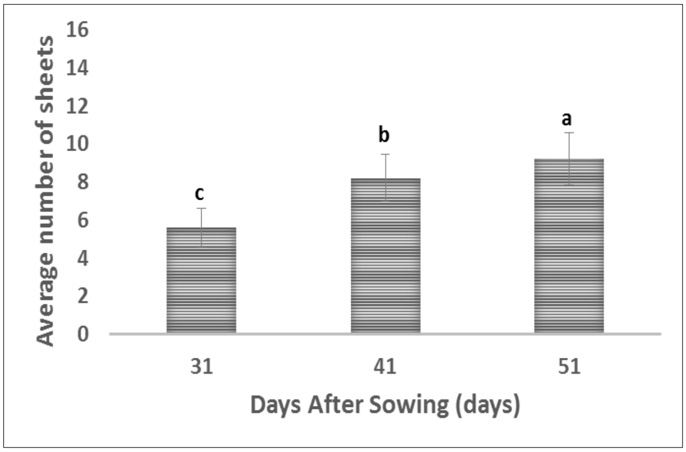

Figure 6: Average number of leaves as a function of day after sowing

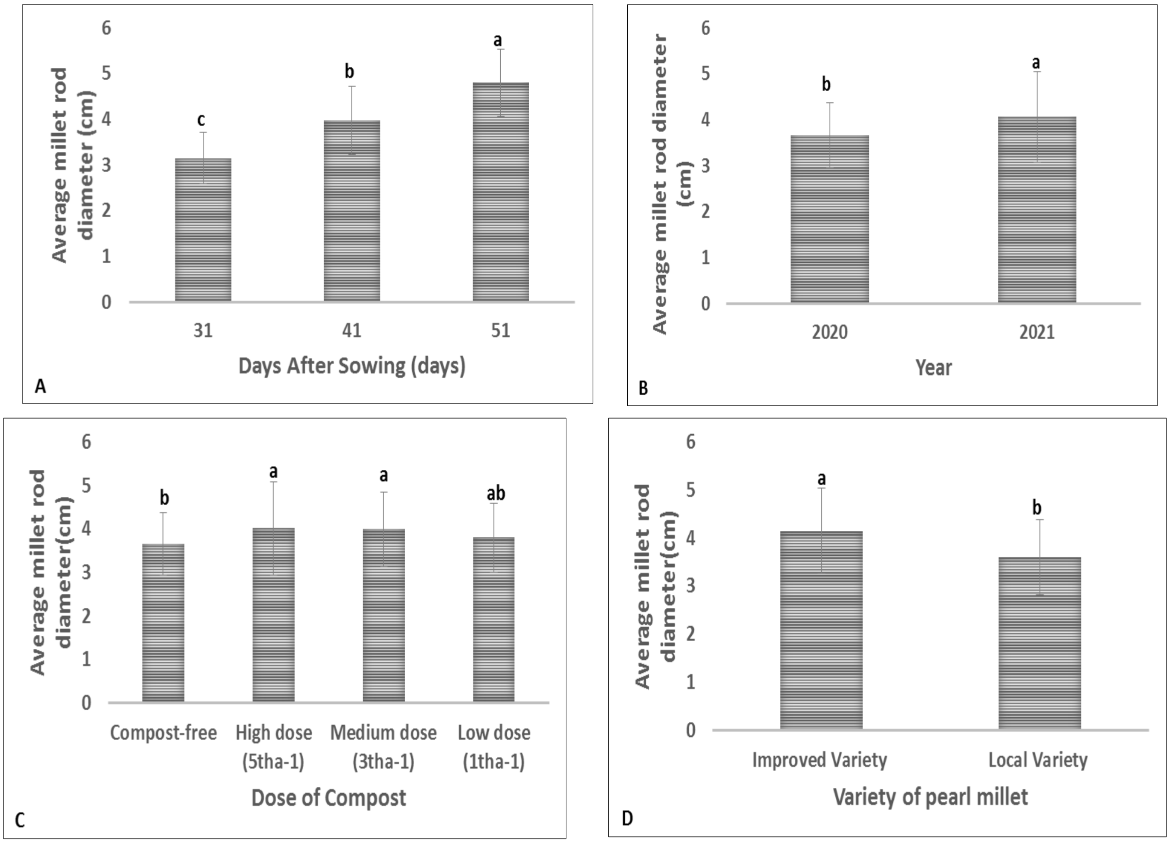

Figure 7: Average diameter of millet stems: A) as a function DAS, B) as a function the year, C) as a function the dose of compost, D) as a function the variety of millet.

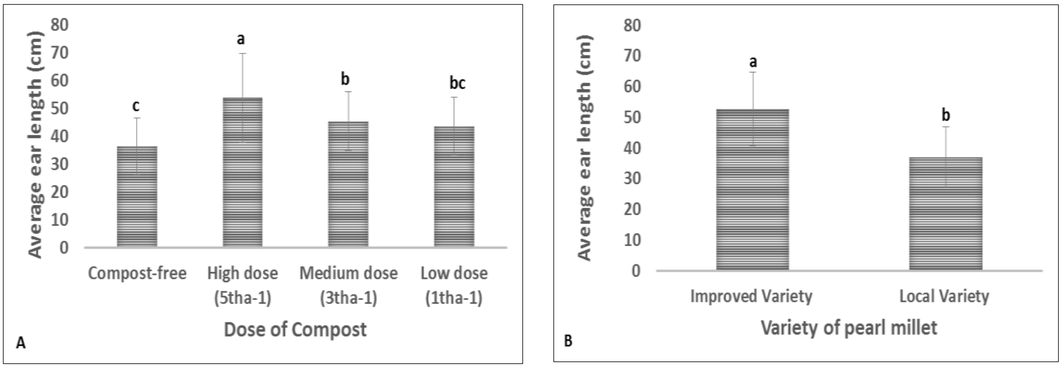

Figure 8: Average length of the cob of millet: A) as a function the dose of compost, B) as a function the variety of millet.

Table 4: Results of the variance analyzes, having a significant effect (p <0.05) on the millet yield parameters (yield and dry matter).

Parameters	Sources of variation	Degree of freedom	Medium square	F test	Probability
Yield	DC	3	3401810,83	16,63	<0,001**
	VM	1	6977116,21	34,11	<0,001**
Dry matter	DC	3	33933786,65	87,291	<0,001**
	VM	1	10007089,12	25,742	<0,001**
	DC * VM	3	1459249,61	3,754	0,02*

DC: dose of compost, VM: variety of millet, *: significant, **: highly significant

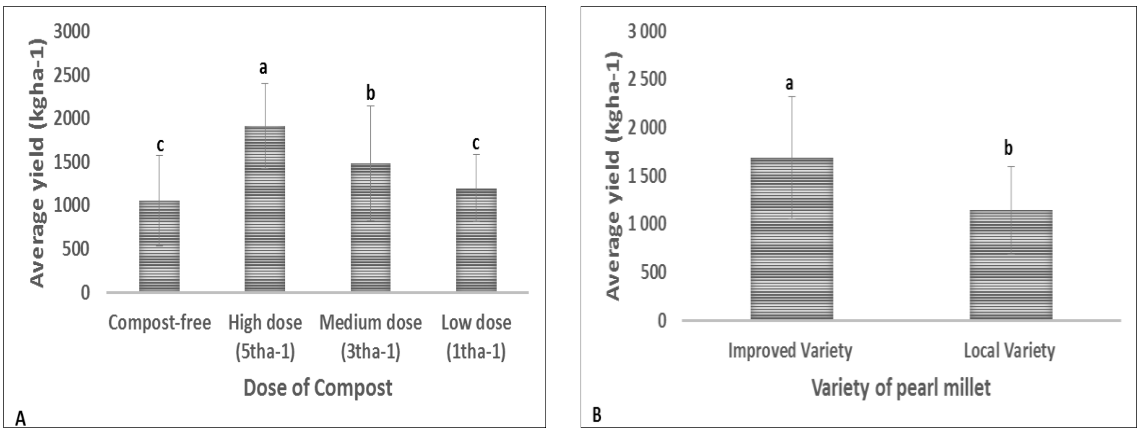

Figure 9: Average grain yield: A) as a function of the dose of compost, B) as a function of the variety of millet.

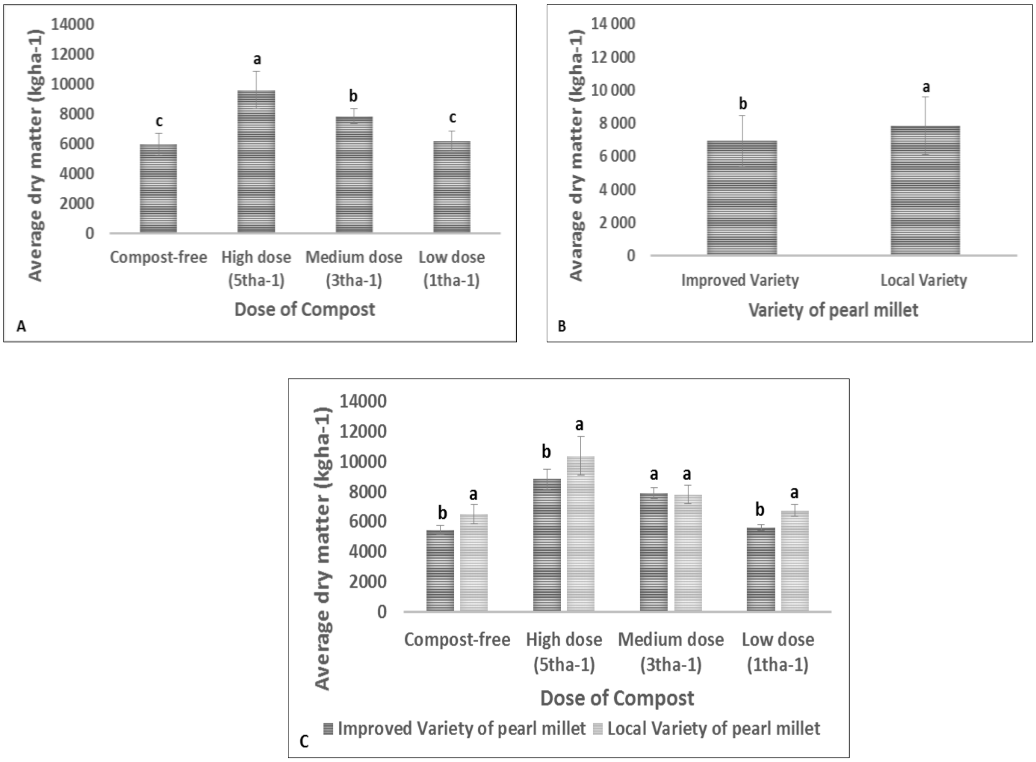

Figure 10: Average dry matter produced: A) as a function of the dose of compost, B) as a function of the variety of millet, C) according to the interaction between the dose of compost and the variety of millet.

DISCUSSION

Millet plant growth

The aim was to convince small producers to use low cost (accessible to all) natural fertilizer (compost) and respectful of the environment, to improve soil fertility and increase durably millet production. Thus, it appears that compost has a significant effect on the growth and yield of millet. Similar results have been reported by Ouédrago et al. (2001) and Sawadogo et al. (2008) who reported that compost significantly increased the growth of sorghum (cereal like millet) in Burkina. The application of organic fertilizers (such as compost) therefore improved the availability of nutrients for millet plants that grow well in height. For Cobo et al. (2002), compost brings nitrogen in organic form to the soil which improves soil fertility and, so the growth of species. Martínez-Blanco et al. (2013) enumerated nine advantages of compost, including supply of nutrients to the soil which would be the basis for improving plant growth. For Fuchs et al. (2008), compost has a positive effect on soil fertility and plant growth and health. Riaz et al. (2001) pointed out that compost helps plants to fight against pathogen attacks and diseases. This would create the conditions for normal and rapid growth. For obtained results on height growth, contributions of at least a medium dose of compost (3 tha^{-1}) is necessary, the low dose (1 tha^{-1}) not statistically different from the control (compost free). However, although the contribution of compost can improve nutrient availability, millet is a plant that can grow on all types of soil and performs best on welldrained sandy loam soils (Bisht et al., 2019), like those on the study site.

The results of this study show that millet is a plant that achieves most of its height growth before the 71st day after sowing. Similar results have been reported by Hamadou et al. (2017) who estimated that the growth phase of millet from emergence to panicle formation is 30 to 50 days after sowing. The differences of a few days observed may come from the fact that these studies are conducted under a strictly rain-fed regime, but this work was conducted by eliminating water stress with additional irrigations. It recommended that all efforts to improve the "millet height growth" factor take place before the 71st day after sowing. Otherwise, the investments will be unproductive and will unnecessarily inflate the cost of production. If it is necessary to use compost to increase the height of the millet, the recommended dose is at least the medium dose (3 tha^{-1}). For maximum height growth, use the high dose (5 tha^{-1}). The average heights of 145,79 cm to 173,98 cm obtained fall within the size range of 0,5 and 3,5 m of millet stem in the semi-arid zone, reported by Pandey et al. (2001) and from 59 to 314 cm found by Loumerem et al. (2008). The difference in height observed between the two seasons is probably due to the residual effects of the application of compost.

No dose of compost influenced the number of tillers. This result is consistent with that of Ndiaye et al. (2019), who reported that tillering is not influenced by organic amendment in a study conducted in Senegal. The number of tillers depends on the stage of growth of the millet plant. At the juvenile stage, the number of tillers is low. It evolves exponentially to attain the maximum then the production drops when the plant begins to wither. These results corroborate those of Hamadou et al. (2017) who showed that the number of tillers becomes greater over time. To obtain many tillers, the effort of using an improved variety of millet is not a solution. Yadav et al. (2024) showed that Indian local varieties of millet contribute to higher tillering than commercial varieties.

The number of leaves produced per millet stem is not influenced by the dose of compost and the variety of millet. But it should be noted that it evolves over time. This growth parameter is not an indicator to test the effect of compost or variety. The diameter of millet stems also changes over time. To obtain a large diameter it is necessary to use at least the low dose of the compost. Sarr et al. (2013) reported that compost improved the neck diameter of the millet stem. The length of millet cobs is influenced by the compost rate and the variety of millet. For a long cob it is necessary to bring the high dose. Using the low dose to increase the length of the cob is a futile attempt as its effect is comparable to that of the control (without compost). With the millet variety, choosing the improved variety will get the longest cob.

Grain and dry matter yield

The use of compost has significantly increased grain yield. This can be explained by the fact that the compost improved the availability of mineral nutrients in the soil, a necessary condition to achieve a good yield. Indeed, in the soil amended with compost, the millet benefited from good nutrition for better production. These results are consistent with those found by Saba et al. (2017) who showed that compost contributes to increasing yields by improving the nutritional status of the soil. In addition, most soils with natural poverty react positively to different practices for adding organic matter such as compost which improves fertility resulting in an increase in yield (Ouattara, 2007). Siddo et al. (2023) also demonstrated a higher yield of millet using organic matter. Ouédrago et al. (2001) on their post reported that the yield of sorghum (millet's sister crop) tripled on plots that received 10 tha^{-1} of compost and increased by 45% on those that received 5 tha^{-1} of compost. Bedada et al. (2014) also reported higher maize yield in composted plots in Ethiopia. Oyewusi and Osunbitan, (2021) obtained higher yields of yam using chicken dung compost extract compared to the control in Nigeria. For Wilson et al. (2019), spreading compost in agricultural fields can increase soil organic matter content and soil productivity. Note also that compost not only acts on the properties of the soil which results in an increase in yield, but it also plays an important role in the health of plants. Thus, good quality compost can be successfully used in biological disease control (Fuchs et al. 2008), which can lead to better yield. In addition, the improved variety increases grain yield (Naoura et al., 2020).

As to produce dry biomass, the medium and high doses of compost made it possible to increase its production. The low dose had no effect on dry matter production. Ouédrago et al. (2001) reported dry matter production from sorghum, higher in plots having received compost than in controls. The variety of millet also had a significant effect on dry matter yield. For high production, the use of local millet variety is recommended. These results corroborate those of Buerkert et al. (2001) who indicated that local millet ecotypes are characterized by significant dry matter production.

CONCLUSION

Ultimately, the present study provided a better understanding of the effect of different doses of compost on the growth and yield of millet in the Sahelian context. Millet is a plant which achieves most of its growth in height before the 71st day after sowing, it is therefore recommended to make every effort to improve this factor before this date, at the risk of making unproductive investments and unnecessarily inflating the production cost. If it happens that it is necessary to use compost to increase the height of the millet, the recommended dose is the so-called high dose (5 tha^{-1}). Considering the results obtained, it appears that most of the parameters studied showed significant effects with the high dose of compost and to a certain extent with the medium dose of compost. Compost is then an alternative to boost millet production. To increase both seed yield and dry biomass yield, a dose greater than or equal to 3 tha-1 must be used. In addition, the choice of an improved variety of millet increases the chance of having large productions of grains and for of dry biomass, the local one. The quantities of compost used, even the high dose, remain within the reach of small producers who can compost part of their crop residues and collect the rest for other use. This work carried out with the representatives of these producers convinced many of them as to the results recorded. They all agree that the low dose is very insufficient to make changes in their production system without adding organic matter. It will be interesting to continue this study on a large scale with an emphasis on training small producers in composting techniques to get a large number to adopt the valorization of organic matter.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

MMA: Supervision of field work, orientation of the study, statistical analyzes of data, writing and correction of the manuscript. ASM: Conduct of the field study and data collection. BSB: Analysis of the compost, statistical analyzes of the data and correction of the manuscript. AM: Supervision, orientation of the study. BM, XM, AG, GF: accepted MMA into their laboratory during the writing of the manuscript and contributed with advice and suggestions for correction of the manuscript.

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REFERENCES

Ambouta KJM, Karimou Barké M, Tidjani AD, Tychon B. 2018. Les cuvettes du Manga, un écosystème unique en milieu semi-aride objet d'une recherche interdisciplinaire et pluri institutionnelle. *Geo. Eco. Trop*., **42**(2): 245-257. DOI: https://hdl.handle.net/2268/242802

Abdoulaye T, Sanders JH. 2006. New technologies, marketing strategies and public policy for traditional food crops: Millet in Niger. *Agricultural Systems,* **90**(1-3): 272-292. DOI: https://doi.org/10.1016/j.agsy.2005.12.008

Agegnehu G, Nelson PN, Bird MI. 2016. Crop yield, plant nutrient uptake and soil physicochemical properties under organic soil amendments and nitrogen fertilization on Nitisols. *Soil & Tillage Research*, **160**: 1-13. DOI: http://dx.doi.org/10.1016/j.still.2016.02.003

Bedada W, Karltun E, Lemenih M, Tolera M. 2014. Long-term addition of compost and NP fertilizer increases crop yield and improves soil quality in experiments on smallholder farms. *Agriculture, Ecosystems and Environment,* **195**(1): 193–201. DOI: http://dx.doi.org/10.1016/j.agee.2014.06.017

Bisht A, Kumar A, Dev Gautam R, Arya RK. 2019. Breeding of Pearl Millet (*Pennisetum glaucum* (L.) R. Br.). In *Advances in Plant Breeding Strategies: Cereals* (Volume 5), Al-Khayri JM, Jain SM, Johnson DV (eds). Springer: Cham; 165-221. DOI: https://doi.org/10.1007/978-3-030-23108-8_5

Buerkert A, Moser M, Kumar AK, Fürst P, Becker K. 2001. Variation in grain quality of pearl millet from Sahelian West Africa. *Fields Crops Research,* **69**(1)1-11. DOI: https://doi.org/10.1016/S0378-4290(00)00127-1

Cobo JG, Barrios E, Kaas DCL, Thomas RJ. 2002. Nitrogen mineralization and crop uptake from surface-applied leaves of green manure species on a tropical volcanic-ash soil. *Biology and Fertility of Soils*, **36**(2): 87-92. DOI: https://doi.org/10.1007/s00374-002-0496-y

Dussert Y, Snirc A, Robert T. 2015. Inference of domestication history and differentiation between early- and lateflowering varieties in pearl millet. *Mol. Ecol*., **24**(7): 1387-1402. DOI: https://doi.org/10.1111/mec.13119

Fuchs JG, Berner A, Mayer J, Smidt E, Schleiss K. 2008. Influence of compost and digestates on plant growth and health: potentials and limits. In *Compost and Digestate: Sustainability, Benefits, Impacts for the Environment and for Plant Production*, Fuchs JG, Kupper T, Tamm L, Schenk K (eds). Zumsteg Druck AG, Frick: Switzerland, 101-110.

Hamadou M, Idrissa S, Mahamadou C, Oumarou S, Valentin K. 2017. Potentialités fourragères du mil (*Pennisetum glaucum* (L.) R. Br): Revue de littérature. *Journal of Animal &Plant Sciences,* **34**(2): 5424 -5447. DOI: http://www.m.elewa.org/JAPS

Hanna WW, Baltensperger DD, Seetharam A. 2004. Pearl Millet and Other Millets. In *Warm-Season (C4) Grasses*, Moser LE, Burson BL, Sollenberge LE (eds). Agronomy Monographs: Madison; 537-560. DOI: https://doi.org/10.2134/agronmonogr45.c

Kadri A, Halilou H, Karimou I. 2019. Culture du mil [*Pennisetum glaucum* (L) R. Br] et ses contraintes à la production: une revue. *Int. J. Biol. Chem. Sci.,* **13**(1): 503-524. DOI: https://dx.doi.org/10.4314/ijbcs.v13i1.40

Lakhdara A, Rabhi M, Ghnaya T, Montemurro F, Jedidi N, Abdellya C. 2009. Effectiveness of compost use in saltaffected soil. *Journal of Hazardous Materials,* **171**(1-3): 29-37. DOI: https://doi.org/10.1016/j.jhazmat.2009.05.132

Leblois A, Quirion P, Alhassane A, Traoré S. 2014. Weather Index Drought Insurance: An Ex-Ante Evaluation for Millet Growers in Niger. *Environ. Resource. Econ.,* **57**: 527-551. DOI: https://doi.org/10.1007/s10640-013-9641-3

Loumerem M, Van Damme P, Reheul D, Behaeghe T. 2008. Collection and evaluation of pearl millet (*Pennisetum glaucum*) germplasm from the arid regions of Tunisia. *Genet. Resour. Crop. Evol.,* **55**(7): 1017-1028. DOI: https://doi.org/10.1007/s10722-008-9309-y

Marteau R, Sultan B, Moron V, Alhassane A. 2011. The onset of the rainy season and farmers' sowing strategy for pearl millet cultivation in Southwest Niger. *Agric. For. Meteorol.,* **151**(10): 1356-1369. DOI : https://doi.org/10.1016/j.agrformet.2011.05.018

Martínez-Blanco J, Lazcano C, Christensen TH, Muñoz P, Rieradevall J, Møller J, Antón A, Boldrin A. 2013. Compost benefits for agriculture evaluated by life cycle assessment. *A review Agron. Sustain. Dev.,* **33**(4): 721-732. DOI: https://doi.org/10.1007/s13593-013-0148-7

Naoura G., Sawadogo N., Djirabaye N., Hassane M.A., 2020. Agronomic performance of improved pearl millet cultivars in southern Chad. *Int. J. Biol. Chem. Sci.*, **14**(9) : 2980-2991. DOI : https://dx.doi.org/10.4314/ijbcs.v14i9.2

Ndiaye A, Ndiaye O, Bamba B, Guèye M, Sawané O. 2019. Effets de la fertilisation organo- minérale sur la croissance et le rendement du « mil sanio » (*Pennisetum glaucum* L. R. Br) en Haute Casamance (Sénégal). *European Scientific Journal,* **15**(33): 1857-7881.

Ouattara K. 2007. Improved soil and water conservatory managements for cottonmaize rotation system in the western cotton area of Burkina Faso. PhD thesis, Swedish University, Sweden, p. 54.

Ouédraogo E, Mando A, Zombré NP. 2001. Use of compost to improve soil properties and crop productivity under low input agricultural system in West Africa Agriculture. *Ecosystems and Environment,* **84**(3): 259-266. DOI: https://doi.org/10.1016/S0167-8809(00)00246-2

Oyewusi TF, Osunbitan JA. 2021. Effect of compost extract processing parameters on the growth and yield parameters of Amaranthus and Celosia Vegetables. *Environmental Challenge,* **5**(1):100302. DOI: https://doi.org/10.1016/j.envc.2021.100302

Ozer P, Hountondji YC, Laminou Manzo O. 2007. Evolution des caractéristiques pluviométriques dans l'est du Niger de 1940 à 2007. *Geo. Eco. Trop*., **33**(n.s.): 11-30.

Pale S, Barro A, Koumbem M, Sere A, Traoré H. 2021. Effets du travail du sol et de la fertilisation organo-minérale sur les rendements du mil en zone soudanosahélienne du Burkina Faso. *Int. J. Biol. Chem. Sci.*, **15**(2) : 497-510. DOI: https://dx.doi.org/10.4314/ijbcs.v15i2.10

Pandey RK, Maranville JW, Bako Y. 2001. Nitrogen fertilizer response and use efficiency for three cereal crops in Niger. *Communications in Soil Science and Plant Analysis,* **32**(9-10): 1465-1482. DOI: https://doi.org/10.1081/CSS-100104206

Pérez-Piqueres A, Edel-Hermann V, Alabouvette C, Steinberg C. 2006. Response of soil microbial communities to compost amendments. *Soil Biology & Biochemistry,* **38**(3): 460–470. DOI: https://doi.org/10.1016/j.soilbio.2005.05.025

Riaz U, Iqbal S, Rafi F, Batool M. 2001. Values of Composting. In *Microbiota and Biofertilizers,* (Volume 2). Ecofriendly Tools for Reclamation, Dar GH, Bhat RH, Mohammad Mehmood MA, Hakeem KR (ed). Springer, Cham; 175-193. DOI: https://doi.org/10.1007/978-3-030-61010-4_9;

Rivero C, Chirenje T, Mac LQ, Martine G. 2004. Influence of compost on soil organic matter quality under tropical conditions. *Geoderma,* **123**(3-4): 355– 361. DOI: https://doi.org/10.1016/j.geoderma.2004.03.002

Saba F, Taonda SJB, Serme I, Bandaogo AA, Sourwema AP, Kabre A. 2017. Effets de la microdose sur la production du niébé, du mil et du sorgho en fonction la toposéquence. *Int. J. Biol. Chem. Sci.,* **11**(5): 2082-2092. DOI: https://dx.doi.org/10.4314/ijbcs.v11i5.12

Sarr PS, Diouf M, Diallo MD, Ndiaye S, Dia R, Guisse A, Yamakawa T. 2013. Effects of Different Types of Litters and Fertilizer Application on Growth and Productivity of Maize (*Zea mays* L.

var. Across 86 Pool 16) in Senegal. *Journal- Faculty of Agriculture Kyushu University,* **58**(2): 259-267. DOI: https://doi.org/10.5109/27356

Sawadogo H, Bock L, Lacroix D, Zombré NP. 2008. Restauration des potentialités de sols dégradés à l'aide du zaï et du compost dans le Yatenga (Burkina Faso). Biotechnol. *Agron. Soc. Environ.*, **12**(3): 279-290.

Siddo SI, Adamou MM, Guisso Maïga DI, Bragé M, Kourido MB. 2023. Production du Mil [*Pennisetum glaucum* (L.) R. Br.] sur des Sols Enrichis par la Boue Résiduaire, la Matière Organique et l'Engrais Chimique. *European Scientific Journal*, **19**(24): 442-454. DOI: https://doi.org/10.19044/esipreprint.6.2023.p442

Sissoko P, Lebailly P. 2019. Les déterminants des rendements du mil et du sorgho avec la technique du microdosage d'engrais. *Rev. Mar. Sci. Agron. Vét*., **7**(2): 213-222.

Termorshuizen AJ, Moolenaar SW, Veeken AHM, Blok WJ. 2004. The value of compost. *Reviews in Environmental Science & Bio/Technology,* **3**(4): 343-347. DOI: https://doi.org/10.1007/s11157-004-2333-2

Varshney RK, Shi C, Thudi M, Mariac C, Wallace J, Qi P, Zhang H, Zhao Y, Wang X, Rathore A, Srivastava RK, Chitikineni A, Fan G, Bajaj P, Punnuri S, Gupta SK, Wang H, Jiang Y, Couderc M, Katta MAVSK, Paudel DR, Mungra KD, Chen W, Harris-Shultz KR, Garg V, Desai N, Doddamani D, Kane NA, Conner JA, Ghatak A, Chaturvedi P, Subramaniam S, Yadav OP, Berthouly-Salazar C, Hamidou F, Wang J, Liang X, Clotault J, Upadhyaya HD, Cubry P, Rhoné B, Gueye MC, Sunkar R, Dupuy C, Sparvoli F, Cheng S, Mahala RS, Singh B, Yadav RS, Lyons E, Datta SK, Tom Hash C, Devos KM, Buckler E, Bennetzen JL, Paterson AH, Ozias-Akins P, Grando S, Wang J, Mohapatra T, Weckwerth W, Reif JC, Liu X, Vigouroux Y, Xu X. 2017. Pearl millet genome sequence provides a resource to improve agronomic traits in arid environments. *Nat. Biotechnol.,* **35**(10): 969-976. DOI: https://doi.org/10.1038/nbt.3943

Wilson C, Zebarth B.J, Burton DL, Goyer C, Moreau G, Dixon T. 2019. Effect of Diverse Compost Products on Potato Yield and Nutrient Availability. *Am. J. Potato Res*., **96**(3): 272-284. DOI: https://doi.org/10.1007/s12230-019-09714-x

Yadav OP, Gupta SK, Reddy SP. 2024. Pearl Millet Breeding for Enhancing Yield and Stability: Strategies, Achievements, and Perspectives. In *Pearl Millet in the 21st Century: Food-Nutrition-Climate Resilience-Improved Livelihoods*, Tonapi VA, Thirunavukkarasu N, Gupta SK, Gangashetty PI, Yadav OP (eds). Springer Verlag: Singapore; 331-360. DOI : https://doi.org/10.1007/978-98199-5890-0_13