ISSN (Online): 2350-0530
ISSN (Print): 2394-3629

International Journal of Research -GRANTHAALAYAH
November 2020, Vol 8(11), 211 – 226
DOI: https://doi.org/10.29121/granthaalayah.v8.i11.2020.2317

VALORIZATION OF SIDA CORDIFOLIA L. BIOMASS IN COMPOST FOR PEARL MILLET (PENNISETUM GLAUCUM) PRODUCTION IN NIGER

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DOI: https://doi.org/10.29121/granthaalayah.v8.i11.2020.2317

Article Type: Research Article

Article Citation: Maman Sadi Souley, Saidou Addam Kiari, Boubé Morou, and Jens B. Aune. (2020). VALORIZATION OF SIDA CORDIFOLIA L. BIOMASS IN COMPOST FOR PEARL MILLET (PENNISETUM GLAUCUM) PRODUCTION IN NIGER. International Journal of Research - GRANTHAALAYAH, 8(11), 211-226. https://doi.org/10.29121/granthaalayah.v8.i11.2020.2317

Received Date: 02 November 2020

Accepted Date: 30 November 2020

Keywords:
Sida Cordifolia L.
Biomass
Composting
Chemical Composition
Pearl Millet Yield

ABSTRACT

Sida cordifolia L. (SC) is an invading species that represents a threat to grazing lands in Niger. In order to enhance this invasive species, we studied the use of this plant for compost-making. First, the study evaluated the development of chemical properties under aerobic composting of SC in pit (P) and in heap (H) composting with two different mixtures. Mixture 1 (M1) contained 75% SC, 20% manure and 5% ash, while mixture 2 (M2) contained 95% SC and 5% manure. Then, the phytotoxicity test of the composts obtained was carried out by evaluating the effects of four different concentrations of compost on germination of pearl millet. The study of the effect of the rates 1000 kg ha^{-1} and 1500 kg ha^{-1} (100g and 150 g $hill^{-1}$) of the different composts on pearl millet yield under field conditions. The composting was undertaken at Molli fishery station and the agronomic tests at the N'Dounga experimental site during two seasons (2018 and 2019). The chemical analysis showed that the composts from M1 were richer in plant nutrients than the M2 composts. All four rates of composts gave germination rates beyond 50% independent of composting method or compost mixture. On both seasons, the 1000 kg ha^{-1} M1P gave the best result in terms of grain yield. In 2018, M1P treatment increased grain yield compared to the control by 652 kg ha^{-1} (105.2%), while in 2019, the corresponding yield increase was 812 kg ha^{-1} (118.02%). Application of 1000 kg M1 compost ha^{-1} corresponded to about 11.1 kg N ha^{-1}, which is more than three times the amount of N applied when using the recommended rate of 20 kg NPK ha^{-1} as micro dosing. This result showed that compost of SC can be used as a supplement to mineral fertilizer for increasing pearl millet yield.

1. INTRODUCTION

Population growth in Niger is about 3%, which means that food production must double in 50 years in order to keep pace with population growth. Farmers are poor and their use of mineral fertilizer is therefore low. There is consequently a need to develop alternative and less costly soil fertility management options. Compost and green manures can be alternatives or supplements to mineral fertilizer. Many studies from the region shows that compost can greatly increase yield. In Burkina Faso sorghum yield increased by 45% as a result of application of 5 Mg compost ha^{-1} and compost application was able to compensate for late sowing (Ouédraogo et al. 2001). In Niger it was found that a compost produced from millet glume and farm yard manure was able to increase pearl millet grain yield by

59.4% when 1.5 Mg compost ha^{-1} was applied as micro dosing (hill placement of manure) (Issoufa et al. 2019). This study also found that application of compost greatly improved the agronomic efficiency of mineral fertilizer and increased soil microbial biomass. A long-term trial in Niger with annual application of organic matter also showed that organic matter application is of vital importance for maintaining the long-term productivity of the soil (Bationo and Buerkert 2001). Application of organic amendments have been found to increase phosphorous availability, stimulate root growth and increase water holding capacity of soil (Bationo and Buerkert 2001). This study also showed that the importance of application of organic amendment was higher in the drier Sahelian zone than in the more humid Sudanian zone. Furthermore, organic amendments were particularly important for increasing pearl millet yields in years with low rainfall.

However, the availability of organic amendment is a problem in the Sahel. In Niger is was shown that only 21% of millet stover produced was available for mulching (Baidu-Forson 1995). Manure is also in low supply as a results of limited number of animals and the quality of the rangeland (Bationo and Buerkert 2001). An additional problem is also that the chemical properties of organic amendment including compost are of poor quality as the chemical properties reflect the soil fertility of the soils from which biomass for the compost was produced (Bationo and Buerkert 2001). There is therefore a need to find alternative biomass sources for producing compost and the use of Sida cordifolia L. (SC) can be an interesting approach because biomass from SC is easily available. *SC* is an herbaceous plant of the family of the Malvaceae. This species was not previously abundant in grazing areas in Niger, but its presence in pastures has increased rapidly in recent decades(Saadou 1990). The species is not grazed by animals and is typically found in animals' passage corridors in agro-pastoral zones (Chaibou 2000). Currently, SC occupies important areas of agro pastoral areas in Niger and is considered an invasive species. SC occupied between 96 and 100% of pasture are in the two villages (Tientergou and Bangou) in Niger (Chaibou 2000).This study therefore accessed the use of SC as material for compost production and its use has as a fertilizer in pearl millet production.

The objective of this study was to valorize the biomass of SC through composting, assess phytotoxicity on germination, and evaluate the effect of compost on grain yield and stover production of pearl millet.

2. MATERIAL AND METHODS

2.1. STUDY ZONES

The study of compost (elaboration and phytotoxicity test) was conducted in 2018 at Molli fishery station located about 35 kilometers at the south-East of Niamey on longitude 2°20' 149'' Est and latitude 13°18'511''North.

The agronomics experiments were conducted during the 2018 and 2019 at the Centre Régional de Recherche Agronomique du Niger (CERRA). Research Station located in N'Dounga (13°25′00′′ N and 2°18′28′′ E) about 22 kilometers at the south-East of Niamey (figure 1).

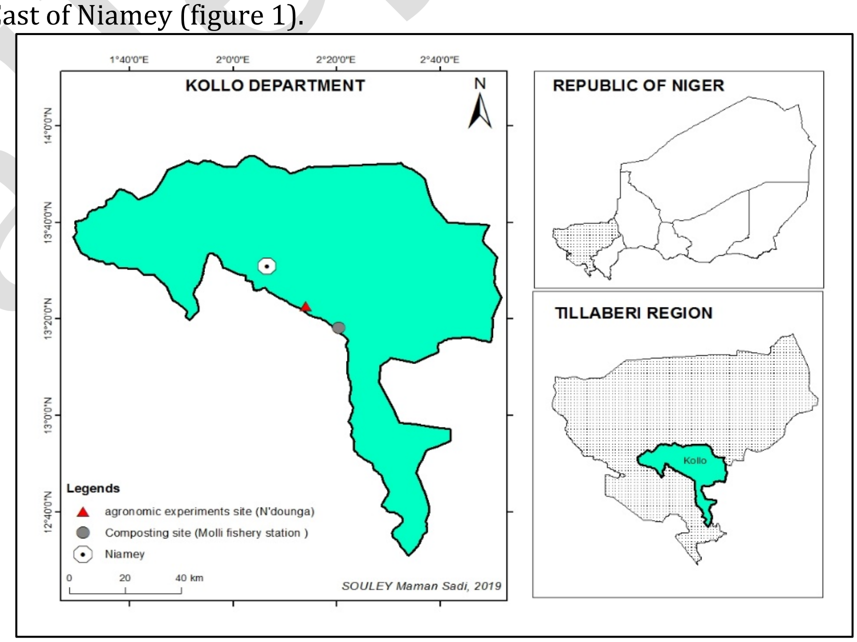

Figure 1: Location of experimental sites.

The climate of the study zone is of Sahelo-Sahelian type with an average yearly rainfall of 482 mm. The average temperatures are around 30°C in the dry season. The soils are classified as Psammentic Paleustalf (FAO, 1988) which is sandy, with moderate to low inherent soil fertility.

The soil in the site (Table 1) are preponderantly sandy, low in organic matter and deficient in both nitrogen and phosphorus (Sadi et al. 2019).

Table 1: Initial soil physical and chemical properties per site (±SE)

Measured parameters	Unit	Mean of values per site (depth 0-20 cm)
pH-H_2O (1:2.5)		6.77±0.1
Carbon	%	0.16±0.01
Total nitrogen	%	0.02±0.002
Available phosphorus	mg kg^{-1}	12.81±8.11
Exchangeable bases		
Ca^{2+}	mg kg^{-1}	7.6±0.08
Mg^{2+}	mg kg^{-1}	1.2±0.40
Na^{+}	mg kg^{-1}	7.13±0.92
K^{+}	mg kg^{-1}	39.9±18.4
Granulometry		
Clay	%	0.72±0.04
Silt	%	4.78±0.41
Sand	%	94.5±1.3

2.2. EXPERIMENTAL MATERIAL

The material used for the composting was dry biomass of SC, organic manure (OM) and ash. The biomass of the SC (stems, leaves, flowers, seeds) was harvested at maturity between October and November 2017. The OM (a mixture of the straw and dejections of bovines) was collected in the village of Molli close to Kollo INRAN station where the test was conducted. The OM was cow dung and crop residues having served to feed the animals. Wood ash was also collected from the Molli village.

The soil used for the phytotoxicity test was collected at N'Dounga research station. where the agronomic experiments were carried out.

The variety of pearl millet Haini Kiré Précoce (HKP) was used in the germination test and in the field experiments. It has a growth cycle of 90 days and plant height varies from 1.9 to 2.0 m. This variety can yield up to 2 t ha^{-1} under good conditions.

2.3. METHODS OF COMPOSTING

The composting methods tested were pit (P) and heap (H) composting under aerobic conditions. The dimensions of the pit were 3 x 3 x 1 m. In the heap method, the diameter of the heap at the ground was 1.5 m and the height 1 m.

Two types of compost mixture were used in this study. Mixture 1 (M1) consisted of 75% of the *S. cordifolia* L. biomass (SCB) + 20% Organic Manure (OM) + 5% ash and mixture 2 (M2) consisted of 95% of SCB + 5% OM. The compost treatments were as follows:

1) M1P: 75% SCB + 20% OM + 5% ash in the pit,
2) M2P: 95% SCB + 5% OM in the pit,
3) M1H: 75% SCB + 20% OM + 5% ash in heap,
4) M2H: 95% SCB + 5% OM in heap.

SCB was first cut into pieces of about 10-15 cm long to accelerate decomposition. The materials were positioned in successive layers (Misra et al. 2005). About 85 liters of water was added before covering the mixture with tarpaulin. Generally, the optimal humidity of the mixture is situated between 50 and 80% of the raw mass (Richard et al. 2002). Every pit/heap was mixed twice per week during the first month (therefore two chambers in the pit). Thereafter, the pit/heap was turned once per week.

During the process of composting, the temperature of the mixtures was measured daily with the help of a probe thermometer. Every month, a composite sample was collected for analysis of pH, carbon, nitrogen, phosphorus and potassium.

The pH was measured with the Mettler-Toledo type MP 225 (ISO 19390 (1994). The total organic carbon was determined according to the method Walkley and Black (Walkley and Black 1934). Total nitrogen was measured using Kjeldahl method (NT 76.05, 1983). Available phosphorus was determined by Bray I method (Van Reeuwijk 1993). Potassium (K^+) was determined with the help of a flame photometer (Lange M7).

2.4. TEST OF PHYTOTOXICITY ON PEARL MILLET

A germination test was undertaken at CERRA Kollo Greenhouse at 25° C to assess the effect of the different types of compost (treatments) on pearl millet germination. A randomized pot experiment with four repetitions was used. The composts M1P, M1H, M2P and M2H were tested in combination with four concentrations of compost (S1=100% compost, S2=75% compost and 25% sand, S3=25% compost and 75% sand and S4=100% sand). The soil was collected at N'Dounga research station. The treatments were tested in pots with 17cm of diameter and 10 cm depth. In every pot, 100 seeds of the pearl millet variety HKP were sown for the germination test. The germination was recorded by counting daily the number of germinated seeds during a 10 days period. Irrigation was provided according to needs of the plants.

2.5. FIELD EXPERIMENT

A field experiment was also undertaken to assess the effects on pearl millet yield of the different types of compost. The treatments were as follows:

1) Control;
2) 1000 kg ha^{-1} M1P;
3) 1500 kg ha^{-1} M1P;
4) 1000 kg ha^{-1} M2P;
5) 1500 kg ha^{-1} M2P;
6) 1000 kg ha^{-1} M1H;
7) 1500 kg ha^{-1} M1H;
8) 1000 kg ha^{-1} M2H;
9) 1500 kg ha^{-1} M2H.

The experiment was completely randomized with four replications. Each plot measured 5 m x 6 m spaced with 2 m between each plot. An alley of 3 m separated the repetitions. The spacing was 1 m within and between rows corresponding to 10 000 hills ha^{-1} as recommended by Institut National de la Recherche Agronomique du Niger (INRAN). The compost was applied at sowing. The plants were thinned to two plants $hill^{-1}$ during the first weeding. At physiological maturity, grain yield and biomass were harvested from the 4 central rows (16 hills) of each plot. The samples were air dried in the sun for two weeks.

In order to appreciate how much productivity improvement was gained by use of the nutrients inputs and how productive the cropping system is relative to its nutrient input, agronomic efficiency was calculated from the formula developed by (Vanlauwe et al. 2011) as follows:

AE-N (kg grain.kg^{-1} N) = $\frac{y-y_0}{F_n}$ where:

AE-N is the agronomic efficiency of nitrogen (kg grain kg^{-1} N),

Y is the grain yield of the fertilized plot in kg ha^{-1},

Y_0 is the grain yield of the control plot in kg ha^{-1} and

F_n is the quantity of nitrogen contained in the applied compost.

2.6. ANALYSIS OF DATA

The data for every variable were tested for their normal distribution with the Ryan Joiner test. An analysis of variance (ANOVA) was used to test for significant differences. The means were separated based on the Tukey's test. The software Excel 2016 and Minitabs 14th edition was used for these analyses.

3. RESULTS

3.1. VARIATION OF THE PHYSICO CHEMICAL PROPERTIES DURING COMPOSTING

A significant variability in carbon, nitrogen and organic matter content was observed during composting process (Table 2). Analysis of the variance showed highly significant differences in physico-chemical elements (C, N, OM) between the composts and between the times (<.001). For pH, no significant difference appeared.

Table 2: ANOVA of physicochemical elements according to composts and time

Compost	Times	Physicochemical elements			
		Carbon (%)	Organic matter (%)	Nitrogen (%)	pH-H_2O
M1P	T1	13.02 ^{i}	22.43^{h}	0.83 ^{c}	8.31 ^{a}
	T2	12.90 ^{h}	22.23 ^{g}	0.80^{b}	8.01 ^{a}
	T3	12.31^{g}	21.21 ^{f}	1.11 ^{e}	8.07 ^{a}
M2P	T1	12.97^{i}	22.35 ^{g}	0.77 ^{b}	8.18 ^{a}
	T2	11.70^{f}	20.16 ^{d}	0.78 ^{b}	7.76 ^{a}
	T3	11.12 ^{e}	19.16 ^{c}	0.88 ^{d}	7.58 ^{a}
M1H	T1	12.00 ^{g}	20.67^{e}	0.63 ^{a}	8.33 ^{a}
	T2	9.51 ^{c}	16.39 ^{b}	0.73^{b}	8.20 ^{a}
	T3	7.90 ^{a}	13.61 ^{a}	0.80 ^{b}	8.09 ^{a}
M2H	T1	9.59 ^{d}	16.52 ^{b}	0.66 ^{b}	8.62 ^{a}
	T2	8.31 ^{b}	14.33 ^{a}	0.68 ^{b}	8.23 ^{a}
	T3	8.25^{b}	14.21 ^{a}	0.83 ^{c}	8.15 ^{a}
Probability					
Compost		<.001	<.001	<.001	NS
Time		<.001	<.001	<.001	NS
Compost*time		<.001	<.001	NS	NS
CV (%)		3.9	3.1	8.0	5.1

***M1 P** = Compost in pit with 75% SCB +20% OM+5% Ash, **M2P** = Compost in pit with 95% SCB +5% OM.*
***M1 H** = Compost in heap with 75% SCB +20% OM+5% Ash, **M2 H** = Compost in heap with 95% SCB+5% OM.*
Same letters within columns indicate no significant differences.

3.2. TEMPERATURE OF COMPOSTS

Temperature (Figure 2 and 3) evolved similarly in the two mixtures and the maximum temperature in both composts was reached in the first week. From the 13rd to 34th day of composting, the temperature dropped in all pits and the maximum temperatures were 55.25°C and 52.3°C for M1 and M2 respectively (Figure 2).

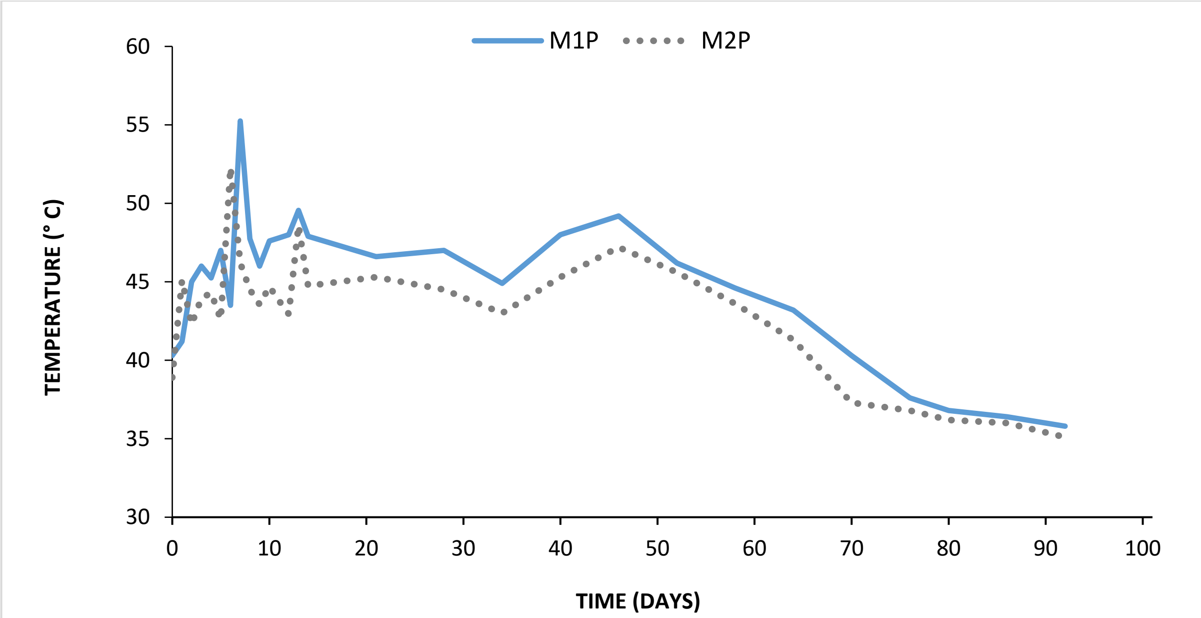

Figure 2: Variation of temperatures during the composting to the level of pits

***M1P** = Compost in pit with 75% SCB +20% OM+5% Ash, **M2P** = Compost in pit with 95% SCB+5% OM.*

In heap composting, the temperatures rose more slowly than in the pit compost and here the highest temperatures were reached in the second week. For heap composting, the highest temperatures reached were 48.3°C for M1H compost and 56°C for M2H.

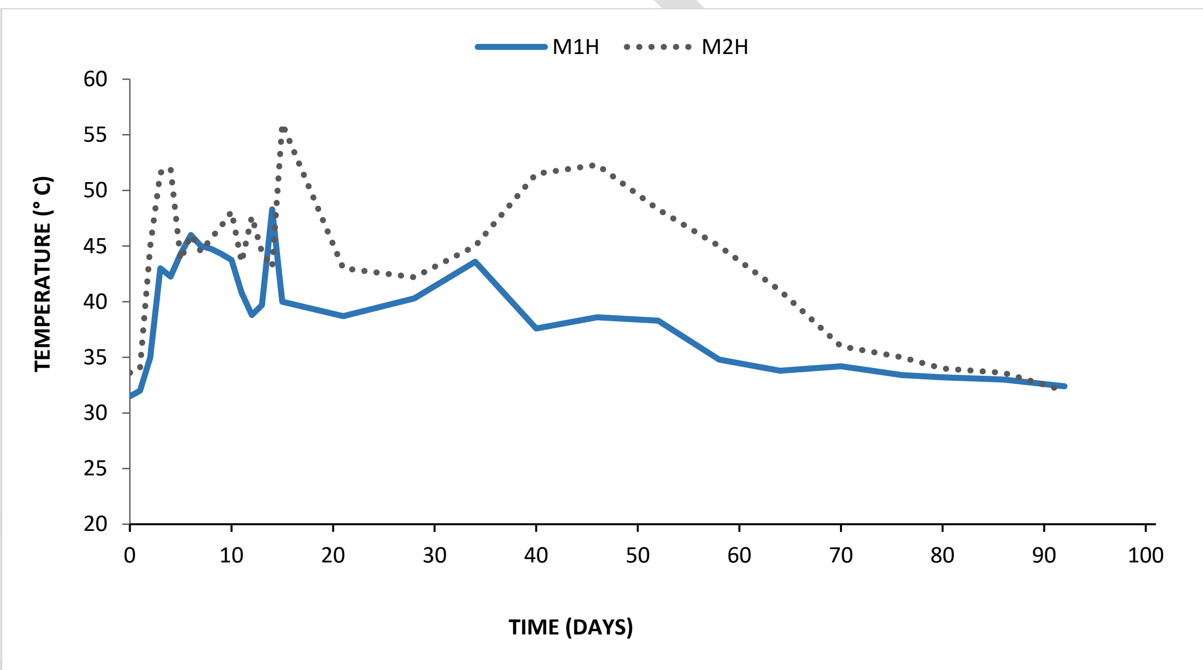

Figure 3: Variation of temperatures during composting to the level of heaps

***M1H** = Compost in heap with 75% SCB +20% OM+5% Ash, **M2H** = Compost in heap with 95% SCB +5% OM.*

3.3. VARIATION OF THE PH

One month after the start of composting, the different mixtures were alkali (pH> 8) (Figure 4). A progressive reduction of pH during the process was observed in all composts, but this reduction is not statistically significant.

During the 90-day period of composting, the pH values of composts in pit reduced from 8.3 to 7.9 for the M1P compost and from 8.17 to 7.58 for the M2P compost. For heap composting, the pH changed from 8.33 to 8.09 for the M1H compost and from 8.61 to 8.14 for the M2H compost.

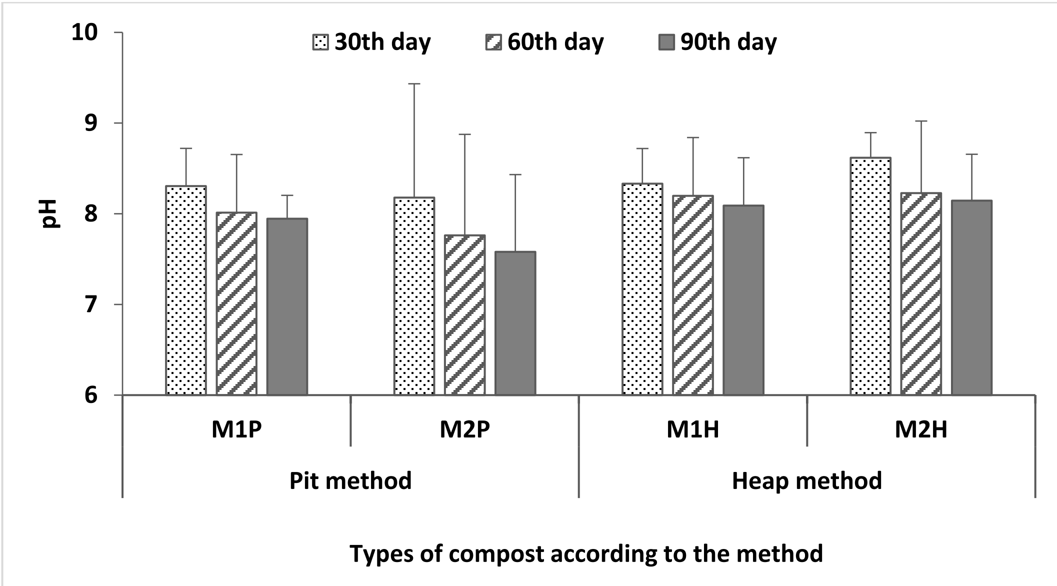

Figure 4: Variation in pH of the composts during the decompositions period

M1 P *= Compost in pit with 75% SCB +20% OM+5% Ash,* ***M2P*** *= Compost in pit with 95% SCB +5% OM.*
M1 H *= Compost in heap with 75% SCB +20% OM+5% Ash,* ***M2 H*** *= Compost in heap with 95% SCB+5% OM.*

3.4. ORGANIC CARBON

The carbon content of the composts was reduced during the 90 days composting period (Figure 4). Statistically, this reduction was significant (p=<.001) at 5% threshold (Figure 5). The carbon content of the M1P compost fell from 13.0% to 12.3% and the M2P compost from 12.97% to 11.12%. The carbon content of the M1H composts and M2H dropped from 12.0% to 7.9% and from 9.59 % to 8.25% respectively.

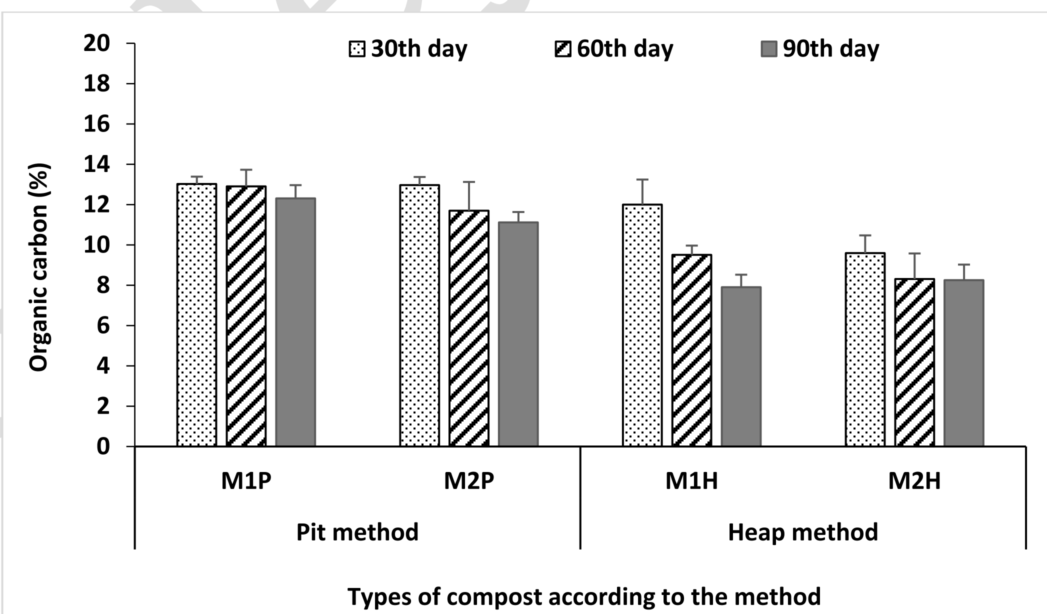

Figure 5: Variations in organic carbon during composting according to the methods and types of mixtures

***M1 P** = Compost in pit with 75% SCB +20% OM+5% Ash, **M2P** = Compost in pit with 95% SCB +5% OM.*
***M1 H** = Compost in heap with 75% SCB +20% OM+5% Ash, **M2 H** = Compost in heap with 95% SCB+5% OM.*

3.5. TOTAL NITROGEN (N)

The nitrogen content differed between the two composts, but also according to the periods of sampling (Figure 6). For the pit method, the nitrogen content increased significantly from the start of composting ($p<.001$). The nitrogen content was highest for the M1P compost. On the 30th day, this compost reached nitrogen content of 0.83% and at the end of the process (90th day), this compost had 1.11% nitrogen. With regard to the M2P compost, its nitrogen content increased between the 30th and 90th day from 0.77% to 0.88%.

The same tendency was observed for heap composting (M1H and M2H). For the M1H compost, the nitrogen content was 0.63%, 0.73% and 0.8% at the 30th, 60th and 90th day respectively. For the M2H compost, this content evolved from 0.66% on the 30th day to 0.83% on the 90th day.

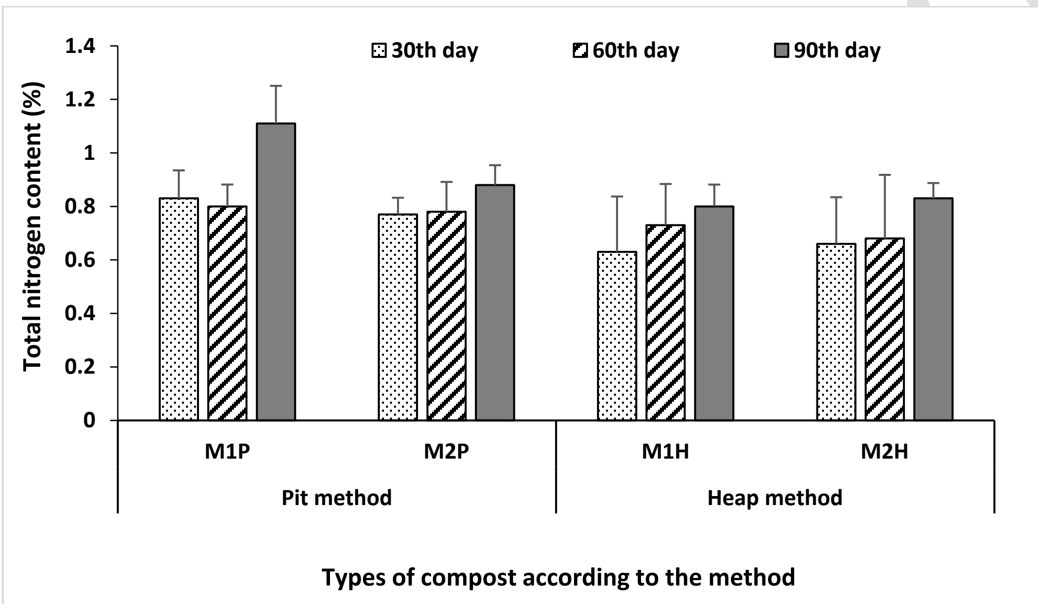

Figure 6: Variation of the total nitrogen during composting according to the methods and the types of mixtures

***M1 P** = Compost in pit with 75% SCB +20% OM+5% Ash, **M2P** = Compost in pit with 95% SCB +5% OM.*
***M1 H** = Compost in heap with 75% SCB +20% OM+5% Ash, **M2 H** = Compost in heap with 95% SCB+5% OM.*

3.6. THE C/N RATIO

The C/N ratio passed from 15.85 at 30 days after composting to 11.24 at 90 days after start of composting for the M1P compost and from 17.06 at 30 days to 12.75 at 90 days for the M2P compost (Figure 7).

For M1H composts and M2H, these ratios passed from 20.8 to 9.99 and from 15.41 to 10.07 respectively.

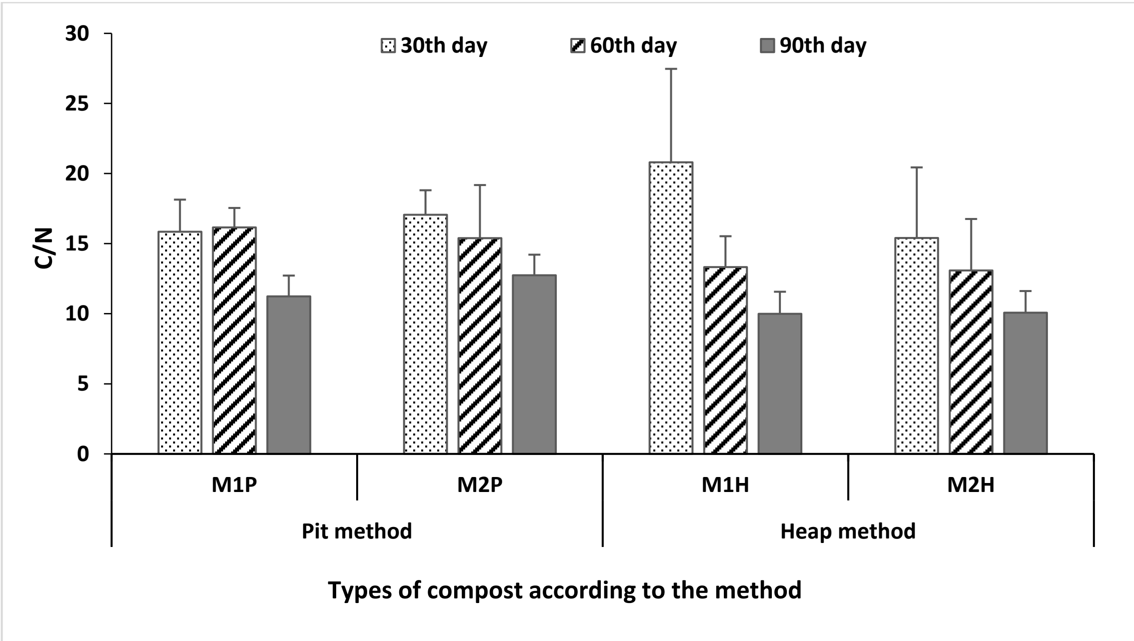

Figure 7: Variation of the C/N ratio during composting according to the methods and the types of mixtures

M1 P *= Compost in pit with 75% SCB +20% OM+5% Ash,* ***M2P*** *= Compost in pit with 95% SCB +5% OM.*
M1 H *= Compost in heap with 75% SCB +20% OM+5% Ash,* ***M2 H*** *= Compost in heap with 95% SCB+5% OM.*

3.7. PHYSICO-CHEMICAL CHARACTERISTICS OF COMPOSTS

The analysis showed highly significant differences with regard to organic matter ($p<.001$), nitrogen ($p = 0.008$), and potassium ($p<.001$) (Table 3) (Sadi et al. 2019). No significant difference was observed for total and assimilated phosphorus and pH-H_2O. The richest compost was the M1P compost and this contained 12.31% C, 1.11% N and 1026 mg K kg^{-1}. The pit method gave a better quality than heap composting as this compost was richer in carbon, nitrogen and available phosphorus than the heap compost.

Table 3: Mean composition in physico-chemical elements of composts (± SE)

Physico-chemical element	Types of composts				F.pr (0.05)	CV (%)	Norme	
	M1P	M2P	M1H	M2H			FAO	AFNOR
pH-H_2O (1 :2.5)	7.95 ^{a} (± 0.26)	7.58 ^{a} (± 0.85)	8.09 ^{a} (± 0.53)	8.15 ^{a} (± 0.51)	0.467	6.7		
Organic matter (%)	21.21 ^{b} (± 1.13)	19.16 ^{b} (± 0.88)	13.61^{a} (± 1.07)	14.21^{a} (± 1.33)	<.0071	6.9	10-30	> 5
C (%)	12.31 ^{b} (± 0.65)	11.12 ^{b} (± 0.51)	7.90 ^{a} (± 0.62)	8.25 ^{a} (± 0.77)	<.001	6.9		
N (%)	1.11 ^{b} (± 0.14)	0.88 ^{a} (± 0.07)	0.80 ^{a} (± 0.08)	0.83 ^{a} (± 0.06)	0.008	11.3	0.4-0.5	> 0.25
Available P (mg kg^{-1})	11.25 ^{a} (± 1.48)	12.76 ^{a} (± 1.46)	9.99 ^{a} (± 1.58)	10.07 ^{a} (± 1.55)	0.112	29.8		
K^{+} (mg kg^{-1})	1026 ^{b} (± 12.5)	975^{b} (± 42.6)	779^{a} (± 51.2)	814^{a} (±14.9)	<.001	4.2		

C/N	11.24 ᵃ (± 1.48)	12.75 ᵃ (± 1.46)	9.99 ᵃ (± 1.58)	10.07 ᵃ (± 1.55)	0.112	14.4	10-15	< 20

***M1P** = Compost in pit with 75% SCB +20% OM+5% Ash, **M2P** = Compost in pit with 95% SCB +5% OM.*
***M1H** = Compost in heap with 75% SCB +20% OM+5% Ash, **M2 H** = Compost in heap with 95% SCB+5% OM.*
***FAO:** Food and Agriculture Organization, **AFNOR**: Association French of Normalization.*
***tot P**= total P and available **P** = Available phosphorus.*

3.8. SAME LETTERS WITHIN LINE INDICATE NO SIGNIFICANT DIFFERENCES

3.8.1. TEST OF PHYTOTOXICITY

The statistical analysis revealed a highly significant difference between the composting methods and the two mixtures on germination (Table 4). The average germination percentages obtained for M1P compost for the S1 substrates, S2 and S3 were 60.3%, 75.0% and 87.5% respectively. Germination decreased with increased amounts of compost in the substrate for all the compost types, but the germination was above 50%, even for the pure compost types.

Table 4: Average of germination rate according to the substrates (compost rate) and the types of compost

Type of compost	Substrates			Control (100% sand)
	S1 (100% of compost)	S2 (sand + 75% of compost)	S3 (sand + 25% of compost)	
M1P	60.25ᵃ	75.00 ᵇ	87.50ᶜ	97.6
M2 P	58.25 ᵃ	74.50 ᵇ	90.25ᶜ	
M1H	50.75 ᵃ	75.25 ᵇ	86.75ᶜ	
M2 H	53.00 ᵃ	68.00 ᵇ	80.50 ᶜ	
F pr.				
Substrates	<.001			
Composts	NS			
Substrates*Composts	NS			
LSD				
Substrates	7.98			
Composts	9.22			
Substrates*Composts	15.97			

***M1 P** = Compost in pit with 75% SCB +20% OM+5% Ash, **M2P** = Compost in pit with 95% SCB +5% OM.*
***M1 H** = Compost in heap with 75% SCB +20% OM+5% Ash, **M2 H** = Compost in heap with 95% SCB+5% OM.*
Same letters within line indicate no significant differences

3.9. EFFECTS OF PREPARED COMPOSTS BASED ON BIOMASS OF THE *SC* ON PEARL MILLET

3.9.1. DISTRIBUTION OF RAINFALL

The distribution of rainfall the cropping season 2018 and 2019 from sowing to the harvesting is illustrated in Figure 8.

In 2018 (figure 8A), a total of 517 mm rainfall was obtained during the 92-day period. The most important rainfall (73 mm) was recorded on the 50th day after sowing (DAS). Between the 7th and 17th DAS, a small dry spell was observed.

The total rainfall from sowing to harvest was 408.2 mm in 2019 at N'Dounga station (figure 8B). The maximal rainfall recorded was 38.8 mm on the 56th DAS.

The two cropping years were characterized by a variation in rainfall distribution. In 2018, 80 days of rain were recorded while in 2019, the season lasted more than 100 days. The rain lasted between sowing and harvest. This variability between the two years is similar to that observed by (Issoufa et al. 2019) during a study carried out in N'Dounga station for the 2013 and 2014.

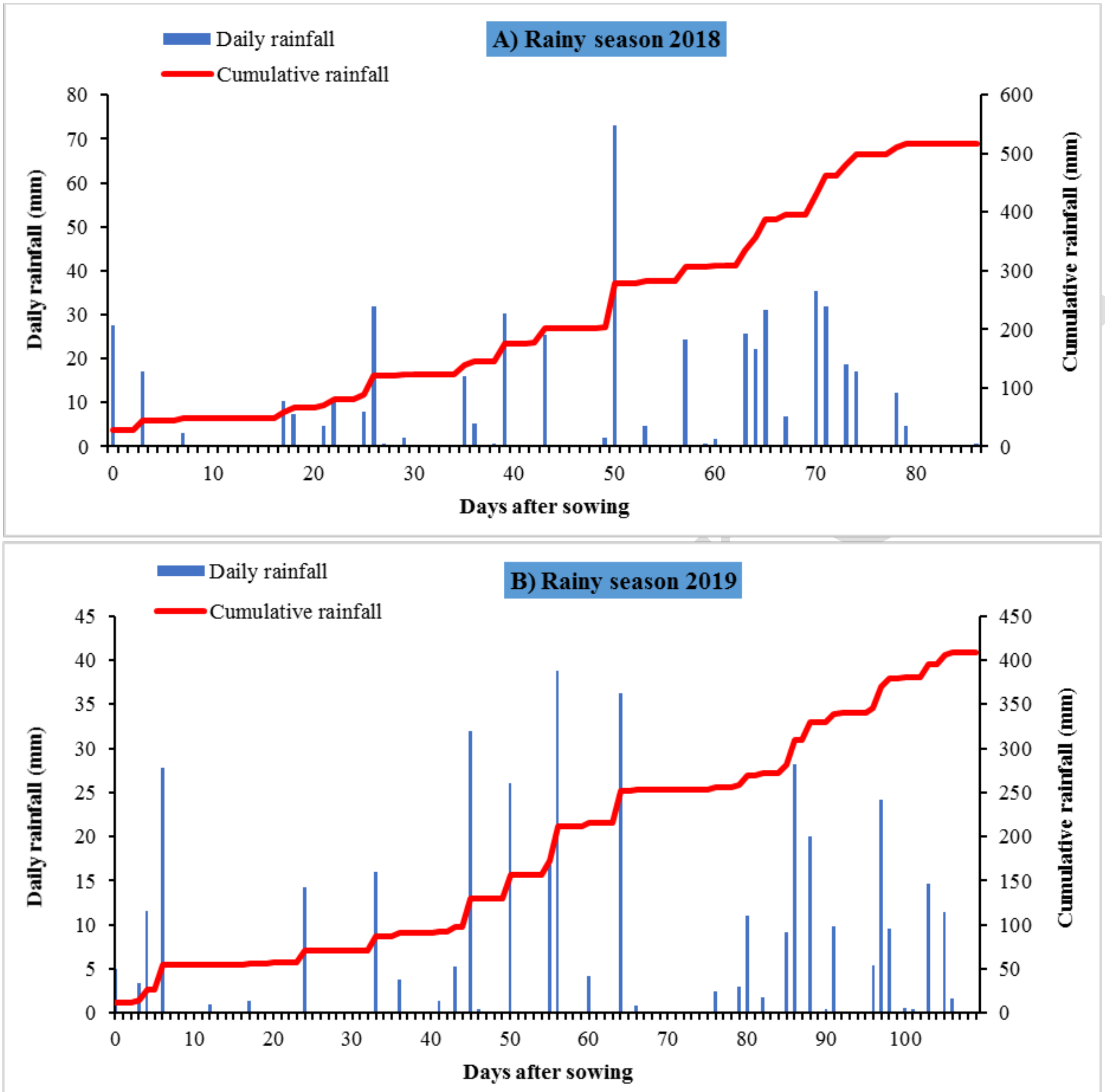

Figure 8: Rainfall distributions for N'Dounga during the cropping season 2018 and 2019
Sources: http://www.fieldclimate.com INRAN REDSAACC-3, Serial number 0020366B

3.10. EFFECTS OF COMPOSTS ON THE MILLET GRAIN YIELD AND THE BIOMASS

Over the two years, the treatments had a significant effect on the grain results (Table 5). The highest grain results were obtained with M1P compost applied at rates of 1000 kg ha^{-1} and 1500 kg ha^{-1}.

In 2018 the M1P treatment increased the yield compared to the control of 652 kg ha^{-1} (105.2%), while in 2019 the M1P treatment increased the grain yield compared to the control of 812 kg ha^{-1} (118.02%). Application of 1000 kg of compost M1P ha^{-1} M1P is equivalent to 11.1 kg N ha^{-1} (1000 kg * 1.11% N). Treatments with pit composting gave better grain yield than heap composting. There was also a tendency for M1 compost to perform better than M2 compost. It was found that 1000 kg ha^{-1} gave better results than 1500 kg ha^{-1} of compost. Treatments and years had significant effects on stem yield.

The treatment of 1000 kg ha^{-1} M1P gave the highest yield in 2018 but also during the 2019 campaign. This treatment increased the yield of the stems compared to the control of 1377 kg ha-1 in 2018, i.e. 77.5% and 1611kg ha^{-1} in 2019 corresponding to 76.13%.

Table 5: Mean yield in grains and in stover of HKP millet according to treatments and sites (±SE)

Treatments	Grain yield (kg ha^{-1})		Stover yield (kg ha^{-1})	
	2018	2019	2018	2019
Control	620±48	688±30	1776±273	2116±309
1000 kg ha^{-1} M_1P	1273±96	1500±97	3153±268	3727±316
1500 kg ha^{-1} M_1P	1128±30	1221±57	2836±276	3563±145
1000 kg ha^{-1} M_2P	856±70	1132±81	1500±193	2663±419
1500 kg ha^{-1} M_2P	790±44	952±52	1565±104	2502±319
1000 kg ha^{-1} M_1H	858±13	922±30	1563±182	2717±419
1500 kg ha^{-1} M_1H	872±41	1006±23	1635±411	2846±221
1000 kg ha^{-1} M_2H	692±27	919±43	1835±141	3093±176
1500 kg ha^{-1} M_2H	685±26	849±25	1517±112	2343±110
Probability (0.05)				
Year (Y)	<.001		<.001	
Treatments (T)	<.001		<.001	
Y x T	NS		NS	
CV	25.8		35.4	

M1 P *= Compost in pit with 75% SCB +20% OM+5% Ash,* ***M2P*** *= Compost in pit with 95% SCB +5% OM.*
M1 H *= Compost in heap with 75% SCB +20% OM+5% Ash,* ***M2 H*** *= Compost in heap with 95% SCB+5% OM.*
Same letters within columns indicate no significant differences

3.11. AGRONOMIC EFFICIENCY OF NITROGEN (AE-N) FOR THE FOUR COMPOSTS

Highly significant differences at 5% were obtained between treatments and years (p<.001).

The agronomic nitrogen use efficiency varied from 10 to 59 kg grain kg^{-1} N in 2018 and from 24 to 78 kg grain kg N^{-1} in 2019 (Table 6). For the two years, the treatment 1000 kg ha^{-1} M1P gave the highest nitrogen use efficiency. In terms of the grain yield, the nitrogen use efficiency was higher in the compost produced in pit as compared to the compost produced in heap.

Table 6: Analysis of the grain yield and the agronomic efficiency of the treatments (±SE**)**

Treatments	N Agronomic Efficiency (N -AE-) kg grain kg $^{-1}$N (dry weight)	
	2018	2019
Control	-	-
1000 kg ha^{-1} M_1P	59±8	78±8
1500 kg ha^{-1} M_1P	47±3	55±5
1000 kg ha^{-1} M_2P	24±6	47±7
1500 kg ha^{-1} M_2P	19±4	32±4
1000 kg ha^{-1} M_1H	24±1	30±2
1500 kg ha^{-1} M_1H	26±3	37±2
1000 kg ha^{-1} M_2H	11±2	30±4
1500 kg ha^{-1} M_2H	10±2	24±2
Probability		
Year (Y)	<.001	
Treatments (T)	<.001	
Y x T	NS	
CV	38.1	

***M1 P** = Compost in pit with 75% SCB +20% OM+5% Ash, **M2P** = Compost in pit with 95% SCB +5% OM.*
***M1 H** = Compost in heap with 75% SCB +20% OM+5% Ash, **M2 H** = Compost in heap with 95% SCB+5% OM.*
Same letters within columns indicate no significant differences

4. DISCUSSION

4.1. EVOLUTION OF THE PHYSICO-CHEMICAL CHARACTERISTICS DURING COMPOSTING

There was no clear difference in maximum temperatures developed in pit composting as compared to heap composing. In pit composing there is probably a cooling effect because the compost is placed below ground, but at the same time the heat loss is lower because the compost is less exposed to air. In heap composting there is probably a greater heat loss because the compost is more exposed to the air. These effects operate in different directions and explain why there is no major difference in maximum temperature between pit and heap composting. However, it was observed that maximum temperature was reached two weeks later when heap composting was used, compared to pit composting.

The maximum temperatures obtained in this study varied from 48.3 for the M1H compost to 56° C for the M2H compost. The maximum temperatures are similar to those obtained by (Tchegueni and Kili 2011). However, typical maximum temperatures in composting is between 60° C and 70° C (Mustin 1987). The low quantity of compost production could be the cause for the low maximum temperatures. Quantities should be greater than 500 kg in order to achieve maximum temperatures higher than 60° C. Such temperatures destroy all the pathogenic organisms (Tchegueni and Kili 2011).

The end temperature in the different composts was close to ambient temperature (44.9°C) which indicates that the decomposition was almost complete (Mustin 1987).

The pH was significantly reduced during the composting period. Soil organic carbon was also reduced during the decomposition process. The microorganisms use the organic matter as a substance for their metabolism, thereby reducing the carbon content of the compost through the release of CO_2 (Francou 2003, Adamou et al. 2018).

During the process of composting, the nitrogen percentage increased in all composts. This could in part be related to the residues of microbes and bacteria that have multiplied especially during the first phase composting (Mustin 1987). It can also be assumed that part of the increase in nitrogen is due to the effect of the release of carbon during the decomposition period which increased the relative content of nitrogen compared to carbon in the compost, thereby lowering the C/N ratio (Tchegueni and Kili 2011, Adamou et al. 2018). Compost to be used as a fertilizer should have a C/N ratio below 15–20 according to the FAO norm, and all the composts produced in this study fulfilled this criterion.

4.2. TEST OF PHYTOTOXICITY ON MILLET

A mature compost will have a non-toxic effect on germinating plants (Tiquia et al. 1997). In this study, different concentrations of the composts were used to test the phytotoxicity on germination of pearl millet. The phytotoxicity test of the composts showed that the incorporation of a dose of 25% of the M1P, M2P, M1H and M2H compost gave a germination rate of 87.5%, 90.3%, 86.8% and 80.5% respectively. The pure composts gave a germination rate of between 50 and 60%. Compost is considered non-toxic when germination is beyond 50% (Luo et al. 2018).

All four types of composts in this study gave germination rates beyond 50%. Therefore, these composts can be applied to millet without causing germination inhibition as the concentration of compost will be low after mixing with the soil, as under field conditions.

The germination and the good quality of sowings indicate that the composts are deprived of substances phenolic which can block germination and growth of the seedlings (Sullivan and Miller 2001).

4.3. PHYSICO-CHEMICAL FEATURES OF PREPARED COMPOSTS

The C/N ratio of composts was relatively low. Composts produced from the mixture of 75% of the SC, 20% of the OM and 5% of the ash have a lower C/N ratio than the compost produced from 95% SC and 5% OM. This result was the same for both pit and heap composting.

Compared to the norms of the FAO, the contents in organic matter and in nitrogen are acceptable. The C/N ratio obtained in this study is close to optimum (Nanéma 2007). This ratio will give a rapid release of nitrogen as this ratio is close to the C/N ratio of soil.

4.4. EFFECTS OF COMPOSTS ON GRAIN YIELD AND BIOMASS OF MILLET HKP

Application of composts improved millet yield compared to the control during both cropping seasons (2018 and 2019). Improved crop yields through composting may be linked to better crop development due to the increased availability of compost nutrients (Badar et al. 2015). Studies by (Fatondji et al. 2009) have also shown an increase in grain and biomass yields from millet resulting from a gradual release of nutrients from composts. M1P compost gave the highest grain yield, possibly because this compost contains more nitrogen and potassium than other composts. This compost is also richer in organic matter, which can over time improve the physical properties of the soil.

Application of compost at a rate of 1000 kg ha^{-1} gave a higher yield than application of 1500 kg ha-1 of compost in both seasons. The rate of 1000 kg ha^{-1} of M1P compost corresponds to 11.1 kg N ha^{-1}. If 20 kg ha^{-1} NPK 15-15-15 is applied as a microdose, the nitrogen application rate is 3 kg N ha^{-1}. The M1P compost will also add approximately 0.0113 kg P ha-1 over the 3 kg P ha^{-1} applied when 20 kg of NPK 15-15-15 ha^{-1} is applied as previously recommended. The nitrogen content is therefore more than three times higher in the treatment of 1000 kg M1P ha^{-1} than when 20 kg of NPK ha^{-1} are applied. In Sudan and Mali, it has been reported that it is possible to use rates as low as 3 kg NPK (15-15-15) ha^{-1} (Aune et al. 2007, Aune and Ousman 2011). This result may also indicate that it is possible to allocate 500 kg of compost ha^{-1} instead of 1000 kg ha^{-1}. It has already been shown that micro-dosing of mineral fertilizers gives good results in the Sahel, but our results also come that it is also possible to practice micro-dosing of organic fertilizer using available local resources. In addition, the results of this study illustrate the principle in precision agriculture that when a resource is in scarcity, as organic matter in this case, it should not be applied by diffusion in the field, but rather applied to the plantation hill (Aune et al. 2017). It is also a less labor intensive and more efficient way.

4.5. AGRONOMIC EFFICIENCY OF NITROGEN (AE-N)

During the two years (2018 and 2019), application of 1000 kg. ha^{-1} of M1P compost gave the highest N-AE with respectively 59 kg of grain kg $^{-1}$ N and 78 kg of grain kg $^{-1}$ N. This can be attributed mainly to the amount of nitrogen contained in this compost (11.1g.kg-1) which is higher than that of other composts. Also, this compost gave the highest results in 2018 (1273 ± 96 kg. ha-1) and in 2019 (1500 ± 97 kg. ha-1). In general, a tangency of the increase in E-N with the decrease in the dose of the compost except at the level of the M1H compost. This could be due to the low proportion of nitrogen contained in this compost which is 0.8% or 8 g. ha^{-1}. Our results are in contrast with those of with those of (Cassman et al. 2002) who report that the reduction of nitrogen fertilizers greatly improves the EAN.

5. CONCLUSION

The results from this study show that it is possible to produce a high-quality compost based on Sida cordifolia (SC) within 90 days. The compost that gave the best yield results consisted of 75% SC, 20% OM and 5% ash (M1P). The compost will not be toxic on germination when applied to the soil. In 2018, the 1000 kg ha^{-1} M1P treatment increased the yield compared to the control by 652 kg ha^{-1} (105.2%), while in 2019 this M1P treatment increased the grain yield compared to the control of 812 kg ha^{-1} (118.02%).

The amount of nitrogen applied in 1000 kg compost ha-1 (100 g compost hill^{-1}) was more than three times the amount applied compared to 20 kg NPK ha^{-1} (2 g NPK hill^{-1}). However, the composts are low in phosphorus making it necessary to supplement with phosphorus from mineral fertilizer or rock phosphates. The results from this study suggest that it should be interesting for the farmers to harvest *Sida cordifolia* L. for compost production, thereby reducing infestation of this invasive weed species. This compost can be used as a supplement to mineral fertilizer.

SOURCES OF FUNDING

The research was funded by the Norwegian Ministry of Foreign Affairs through Norwegian embassy in Bamako, Mali.

CONFLICT OF INTEREST

The author have declared that no competing interests exist.

ACKNOWLEDGMENT

The authors would like to thank the Department of International Environment and Development Studies, Norwegian University of Life Sciences, Ås, Norway.we also thank CARE and INRAN in Niger.

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