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Full Length Research Paper

Short-term effects of conjunctive use of municipal solid waste compost and inorganic fertilizer on soil properties and maize productivity in Northern Benin

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Abstract

This study shows how low-cost composts can increase agricultural productivity in the maize-based cropping systems in Northern Benin. The treatments were consisting of eight treatments resulting of combination of two composts obtained under two composting process (pile and trench composting) and mineral fertilizer. The average value of the chemical characteristics of the composts show that certain elements contained in the composts, such as organic element, azote, C/N and potassium, are in acceptable quantity. Soil nutrient content were significantly increase 1.6 to 1.8 times in TC_{20}, PC_{20} and PC_{10}+ $RD_{1/2}$ respectively compared with the control, whereas treatments TC_{10}+$RD_{1/2}$, PC_{10}+$RD_{1/4}$ and TC_{10}+$RD_{1/4}$ show similar effect. The plant height, number of leaves and leaf area index were significantly taller in treatments PC_{20}, PC_{10}+$RD_{1/2}$ and TC_{10}+ $RD_{1/2}$ than the control. The grain and straw yields recorded were significantly higher in plots treated with TC_{10}+$RD_{1/2}$, followed by TC_{20}, TC_{10}+$RD_{1/4}$ and RD, whereas the lowest yields were obtained in the control. As individual applications, the 100% inorganic fertilizer treatment (RD) was similar to the organic source, but the combination of the two at half the dosage out yielded all other treatments. Increases in soil nitrogen, available P, and K were observed in treatments with compost. It appears that the short-term and rational conjunctive use of mineral fertilizer with compost could start smallholder farmers on a trajectory to more yields as well addressing environmental issues of arbitrary fertilizer use.

Keywords: Composts, Municipal wastes, Productivity, Maize, Northern Benin

INTRODUCTION

In Benin, and in the Northern Benin particularly, maize is the most important staple food, but its productivity is still very low (ranging from 500 to 1000 kg/ha) and far below the potentials (3 - 5 t/ha) (Azontondé et *al.*, 2005). In this region, the agricultural system is practiced according to the slash-and-burn technique and crop productions are commonly severely limited by a shortage of inputs. The evolution of this form of agriculture is classic in West Africa, as well as in other developing countries. It leads to an increase of cultivated lands to the detriment of the fallowed areas and the natural savannah's. However, this practice is no longer used, due to the increased population densities and the development of cash crops which have drastically reduced land availability, leading to a net reduction of the fallow period (Stoorvogel and Smaling, 1990; Tilander, 1996). Land fallowing and crop rotation practices, traditionally used to maintain soil fertility, were gradually reduced due to high population pressure and limited availability of cultivable land. Farmers nowadays cultivate the same piece of land for a long time. This over-cultivation gradually led to low inherent soil fertility, soil degradation through nutrient and organic matter depletion.

To overcome the problem of nutrient deficiency and to increase maize yield, the use of mineral fertilizers has been promoted. However, chemical fertilizers are expensive and small farmers cannot afford to use these fertilizers in appropriate amount and balanced proportion because the recommended rates are often too costly and involve a high financial risk. Under such condition, the development of innovative low-input technologies that can concurrently replenish soil nutrients as well as improve rainfall use efficiency, in order to increase crop productivity is needed.

Many studies showed that application of organic amendments such as animal manures, crop residues at reasonable rates improves soil structure and its capacity to store water and increases available soil nutrient levels, and this consequently increases plant growth and yield (Aggelides and Londra, 2000; Ouedraogo and *al.*, 2001; Kowaljow and Mazzarino, 2007; Lillywhite et *al.*, 2009; Lopedota and *al.*, 2013; Motta and Maggiore, 2013). However, these resources are now insufficient to cover farmer's needs (fast increasing acreage, competing uses). A credible alternative is the use of cheaper amendments such as municipal waste compost, which can be available at low cost to most semi-subsistence farmers.

Use of municipal solid waste (MSW) compost is common practice to improve the physicochemical and biological properties of unproductive soils by providing organic matters and macronutrients for crops (Carbonell et *al.,* 2011). Moreover, the rationale for the use of municipal solid waste compost as a management strategy is based on the fact that they do not only provide a substantial amount of plant nutrients, but it is also an environmentally and economically sound alternative since it provides a locally available source of nutrients and reduces the risks of human health, water and soil pollution (Laos and *al.*, 2000; Douglas and *al.*, 2003; Kowaljow and Mazzarino, 2007; Weber and *al.*, 2007) and have a significant liming effect on soil acidity (Wong and Swift, 2003; Tang et *al.*, 2007). In Benin, the town of Cotonou has the highest waste generation of 300 kg per capita, which results in the production of 3600 tons of wastes per day (Amadji, 2004). In Parakou, a town located in the Northern part of Benin, a total of 34000 tons of waste of different nature are produced in 2010, by 201276 inhabitants (Gan, 2010). At the moment, 40% of the wastes in Parakou are disposited in landfill sites. Some general trends such as the high content of organic matter (50 % - 90 %) and their low heavy metals provide an opportunity for exploitation through composting processes (Senesi and Plaza, 2007; Pleissner et *al.*, 2014).

However, the usual application rate of manure (> 40t/ha) is not environmentally and economically viable for many poor farmers (Assogba-Komlan et *al.*, 2007). The combined application of organic inputs and mineral fertilizer at reduced rate could be an interesting alternative for regulating soil fertility while improving crop productivity at a low cost. Most existing studies reported substantial positive effects of the combined application of organic amendments and mineral fertilizers in addressing soil fertility depletion by preventing soil acidification and improving water and nutrient-holding capacity of the soil, thereby minimizing leaching losses and maximizing the agronomic efficiency of applied nutrient inputs (Amusan et *al.*, 2011; Chivenge et *al.*, 2011; Kihara et *al.*, 2011; Vanlauwe et *al.*, 2011). Apart from enhancing crop yield, the practice has a greater beneficial residual effect than the sole use of mineral fertilizer or organic materials (Cela et *al.*, 2011; Demelash et *al.*, 2014).

To date, information on the agronomic value of municipal waste solid composts (MSWC) in Benin and on ferruginous tropical soils of Northern Benin particularly is scarce to our knowledge. In this context, much research is still needed in order to provide data and guidelines on the composting methods and the utilization of the resulting compost. Therefore, it is necessary to obtain information regarding the proportion of compost macro and micro-nutrients that can be used by crops. On the light of these considerations, a short-term study was carried out under maize crop in Parakou municipality (Northern Benin) with the following aims: (i) assess the suitability of urban bio-solid waste compost under two home composting process to supply major plant nutrients (N, P, K); (ii) evaluate and compare the effects of mineral fertilizers, composts and their combination on the growth, yield and nutrient uptake of maize; and (iii) assess the comparative effectiveness of the composts in improving soil chemical properties and find out best combination of mineral fertilizer and compost for maximum maize production.

MATERIAL AND METHODS

Experimental site

The experiment was conducted during 2013 rainy season (June to October) at the Teaching and Research Farm of the Faculty of Agronomy in the University of Parakou, Northern Benin (latitude 09°20'16.8''North; longitude 002°38'54'' East and 353 m altitude). The climate is soudanian tropical type with one rainy season characterized by 800-1100 mm mean annual rainfall and 24 – 31 °C mean monthly temperature. The rainy season extends from May to October. The relative humidity average was 18 – 99 %.

The original soils of the site are ferruginous tropical (lixisols according to USDA textural classes) and sandy loam. Soil chemical properties (0 – 20 cm depth) were: pH_{H2O} and pH_{KCl} 6.6 and 6.5 respectively; available K, available P (Bray-1) and total-P 0.2 cmol/kg, 14 and 25.9 mg/kg respectively; organic-C and total-N 0.5 % and 0.06 % respectively.

Compost production

The preparation of composts was done using selected organic fraction of urban solid waste or biowaste from markets, restaurants (include cheap restaurants) and hotels from Parakou city. The organic material composted included crop wastes (leaves and vegetable scrap, fruits), food wastes and animal wastes (egg shell, sheep and cow droppings residue in paunch). Any metallic objects, battery and plastic were removed from the pile of the organic material to be composted. These organic materials were composted under two processes:

i Pile composting (PC): The compost pile volume was 0.7 m^3. The pile was done under trees to avoid interference from heavy rain. These piles of organic material were constituted of alternate layers. All of these constituents were mixed up during the first turning over. It was considered matured in the 3th month of composting based on the physical appearances such as very dark in color, having smell of the soil, the pile was of ambient temperature and materials became friable.

ii Trench composting (TC): This compost was produced to be used first as growing medium, then as mulch to improve soil properties. Organic wastes were placed in 6 trenches (2 m length, 1.5 m width and 1.5 m depth). The pits were watered every week. After three months the compost was left on the soil as mulch in natural condition. After the three month of composting, it formed an organic layer of 7 cm thick on the soil.

The composts were turned 3 times in the first month and once in second and third month.

Experimental design

The treatments consisted of eight treatments resulting of combination of two food waste composts, obtained under two composting process (pile and pit composting) and mineral fertilizer:

1. No fertilizer (Control);
2. 20 t/ha of pile compost (PC_{20});
3. 20 t/ha of trench compost (TC_{20})
4. Full recommended dose of mineral fertilizer (150 kg/ha NPK + 100 kg/ha urea) (RD);
5. 10 t/ha of pile compost + half of recommended dose (75 kg/ha NPK + 50 kg/ha urea) (PC_{10}+ $RD_{1/2}$);
6. 10 t/ha of trench compost + half of recommended dose (75 kg/ha NPK + 50 kg/ha urea) (TC_{10} + $RD_{1/2}$);
7. 10 t/ha of pile compost + quarter of recommended dose (37.5 kg/ha NPK + 25 kg/ha urea) (PC_{10}+ $RD_{1/4}$);
8. 10 t/ha of trench compost + quarter of recommended dose (37.5 kg/ha NPK + 25 kg/ha urea) (TC_{10}+ $RD_{1/4}$);

The treatments combinations were laid out under randomized complete block design with three replications. Plot size was 5 m x 4 m with guard rows of 2 m.

Crop management and data collection

Maize seeds (DMR-ESZR variety of 90 days cycle) were sown manually by putting 2–3 seed per hole with a spacing of 80 cm – 40 cm for row-to-row and plant-to-plant, respectively. Thinning of seedlings was done from 7 to 10 days after sowing (DAS). Earthing up was achieved at 45 DAS with small hoe. During the growing season, the field was weeded three times using hoes. The crop was harvested at 110 DAS. Total quantity of P and K was applied at sowing and N was applied at two split, one at 15 days after sowing and the second at 45 days after sowing. Compost were spread in the field and ploughed in 15 days before sowing.

Rainfall data were recorded by means of a rain gauge located at the experimental site. At tasseling stage, plant height, number of leaves, leaf area index (LAI) and above-ground biomass of maize were measured on five plants randomly selected and tagged from three rows in each plot. Individual leaf area was estimated non-destructively from leaf length (l, cm), from the collar to the tip of fully expanded leaves, and from where a leaf could be seen in the whorl of expanding leaves to the tip; and leaf width (w, cm) at the widest point. Senesced leaves were not measured. Total plant leaf area was calculated by summing the products (l x w) of each leaf from a plant and multiplying the total by 0.75 (Elings, 2000).

Maize grain, stover yields and harvest index were determined at harvest from net-plots of 3 rows x 3.8 m. At harvest, the number of plants/hill and number of cobs/plant were counted. To determine grain yield and dry matter yield, samples of straw and non-spared cobs were oven-dried at 70 °C for 48 h and weighed. Yield components were also measured (e.g., 1000 grains weight, cob length and diameter).

Yield and nutrient uptake/efficiency calculations were done using the following expressions:

- Dry matter factor = sample dry weight / sample fresh weight
- Yield (kg DM/ha) = dry matter factor x (total fresh weight x 10 000) / Effective area.
- Harvest Index, HI: HI = (Economic yield x 100) / Biological yield Where: Economic yield = weight of seeds and Biological yield = above ground biomass.

Chemical analysis of the composts, grain and the soils

A quantity of 400 g of the matured composts were sampled after sieving *i.e*. after three months of composting process and sent to the laboratory, where they were dried at 60 °C until constant weight and stored for chemical analyses. The analyses included organic matter content (by incineration at 450 °C); total nitrogen (micro- Kjeldahl distillation in a mixture of $H_2SO_4^-$ selenium followed by distillation and titration); pH_{H2O} (using glass electrode in 1:2.5 v/v soil solution); total phosphorus (after calcinations) total potassium (after calcinations and K^+ in the ash by flame photometer) ; bulk density (determination of the fresh weight of a known volume of compost, this was done in the field after sieving the compost), water holding capacity (oven dry method) (Page et *al*., 1982).

The soils were sampled in each elementary plot before the application of the fertilizers and at the harvest period, from five cores, with a post-hole auger according to two diagonals crossed at the depth of 0 – 20 cm, mixed, dried and sieved at 2 mm of mesh for the analyses in the laboratory. The analyses were performed in the Laboratory of Soil Sciences of the National Institute of Agricultural Research of Benin (INRAB). Analyses included particle size distribution (by sieve and pipette method after removal of organic matter, carbonates and iron oxides), pH_{H2O} and pH_{KCl} (using glass electrode in 1:2.5 v/v soil solution), total N (Kjeldahl method, digestion in a mixture of $H_2SO_4^-$ selenium followed by distillation and titration), exchangeable cations (with 1 N ammonium acetate at pH 7, then Ca^{2+} and Mg^{2+} were determined by Atomic Absorption Spectrophotometry and K^+ was determined by flame photometer), CEC (1 N ammonium acetate at pH 7, desaturation of clay-humus complex and determination of desorbed ammonia by micro-Kjeldahl distillation), organic carbon (Walkley-Black, 1934, wet oxidation with $K_2Cr_2O_7$ procedure), available phosphorus (Bray-1 method) and total phosphorus after calcinations (Dabin, 1967). Total nitrogen content in these dry samples is determined by the Kjeldahl method, which is a mineralization in sulfuric acid in the presence of Se-K_2S_{O4}-CuS_{O4} (Bremner and Mulvaney, 1982).

To study maize grain nutrient uptake ten grain samples were collected per plot in three replications at harvest. Samples were cleaned, dried at 65 °C for 48 h; weighed and ground to pass a sieve of 1 mm mesh size. Subsamples of 5 g were analyzed for total N, P and K, following a digestion according to the Kjeldahl method (Houba et *al*. 1995). Total nitrogen content in these dry samples is determined by the Kjeldahl method, which is a mineralization in sulfuric acid in the presence of Se-K_2S_{O4}-CuS_{O4} (Bremner and Mulvaney, 1982). Total P was determined with the colorimetric method based on the phosphomolybdate complex, reduced with ascorbic acid and total K with flame emission spectrophotometry.

Efficiency parameters of nutrients such as uptake, % nutrient use efficiency (NUEN), agronomic efficiency (AEN) and physiological efficiency (PEN) were calculated (Abbasi et *al*., 2012):

- N uptake(kg ha^{-1}) = N content in plant sample × dry biomass yield ha^{-1}
- % Nitrogen use efficiency (NUEN) = (total N uptake in N fertilized plot − total N uptake in control plot) * 100 / quantity of N fertilizer applied in fertilized plots
- Agronomic efficiency (AEN)(kg grain per kg N applied) = (grain yield in fertilized plot – grain yield in control plot)/ quantity of N fertilization
- Physiological efficiency (PEN) (kg grain per kg N uptake) = (Grain yield in N fertilized plot − grain yield in control plot) / (total N uptake in fertilized plot − total N uptake in control plot).

Statistical analysis

The data were subjected to one-way analysis of variance (ANOVA) using SPSS version 21 software. Turkey's test (HSD at P.0.05) was performed to test the significance of difference between the treatments.

RESULTS

Characteristics of the composts

Physicochemical parameters and nutrient content were analyzed from pile and trench composting systems processing of organic fraction of urban bio-solid waste. The final characterization of these composts is presented in table 1. Statistically significant difference was found between the pH_{H2O} in both composts. Trench compost (TC) indicated pH_{H2O} fairly neutral while pile compost was slightly alkaline in reaction. Trench compost showed almost the highest chemical (Table 1) properties. Organic-C was significantly ($P < 0.01$) higher (31.8 g/kg) than pile compost (23.3 g/kg), total-N was almost significantly ($P < 0.01$) higher (3.4 g/kg) than pile compost (2.8 g/kg). Likewise, the organic matter content was significantly ($P < 0.01$) higher (5.5 %) than pile compost (4.0 %). The total-P contents was almost similar in the two types of compost produced with food wastes while available P and total-K content were significantly ($P < 0.01$) higher in trench compost (9.2 and 1.6 g/kg respectively) than pile compost (7.8 and 1.3 g/kg).

Treatment effects on the measured soil properties

Soil chemical properties after harvesting maize as influenced by the different treatments were presented in table 2. A significant ($P < 0.01$) increase of main macronutrient content was registered in the plots where the composts were applied compared with the control plot. Soil pH_{H2O} were slightly neutral and are similar regarding the different treatments ($P > 0.05$). The soil organic carbon and matter content were similar with the

Table 1. Main characteristics of the mature composts as influenced by composting process (mean values ± standard deviation)

Properties	Types of compost		Analysis of variance (*P*)
	Pile compost (PC)	Trench compost (TC)	
pH_{H2O}	7.8 ±0.2	7.3 ± 0.1	**
Organic-C ($g.kg^{-1}$)	23.3±0.4	31.8±0.1	***
Total-N ($g.kg^{-1}$)	2.8 ±0.1	3.4±0.3	**
C/N	8.2±0.1	9.3±0.2	**
Total- P ($g.kg^{-1}$)	19.3±1.1	19.8±2.2	ns
P-Bray-1 ($g.kg^{-1}$)	9.2±1.2	7.8±1.9	***
Total K ($g.kg^{-1}$)	1.6±0.9	1.3±0.3	*
Ca ($g.kg^{-1}$)	2.2±0.6	2.6±0.4	*
Mg ($g.kg^{-1}$)	0.6±0.01	0.7±0.03	**
Organic matter (%)	4.0±0.4	5.5±1.1	***

; **, * = Significant at the P ≤ 0.05; 0.01 and 0.001 levels, respectively; ns = not significant.*

Table 2. Soil chemical properties as affected by conjunctive use of Municipal solid waste compost and mineral fertilizer

Treatments	pH_{H2O}	Organic-C(%)	Total-N (%)	Total- P ($mg.kg^{-1}$)	P Bray-1 ($mg.kg^{-1}$)	K($Cmol.kg^{-1}$)	OM (%)
Soil initial status	6.6	0.5	0.06	25.9	14	0.16	1.2
Control	6.5	0.5	0.05a	20.4a	4.7a	0.12a	0.9
RD	7.2	0.6	0.07a	31.3ab	14.6c	0.14a	1.0
PC_{20}	7.2	0.7	0.09b	76.5c	15.6c	0.21ab	1.3
TC_{20}	7.4	0.8	0.08b	39.4b	15.3c	0.27b	1.4
PC_{10}+ $RD_{1/2}$	7.3	0.7	0.09b	28.2ab	24.0d	0.39b	1.2
TC_{10} + $RD_{1/2}$	7.5	0.8	0.07ab	38.3b	23.5d	0.79c	1.3
PC_{10} + $RD_{1/4}$	7.0	0.7	0.07ab	82.5c	10.3b	0.24b	1.2
TC_{10} + $RD_{1/4}$	6.8	0.7	0.08b	70.8c	10.9bc	0.13a	1.2

Means with the same letter within a column are not significantly different using Tukey's test (HSD) at (P≤0.05); PC_{20}: 20 t/ha of pile compost; TC_{20}: 20 t/ha of trench compost; RD: Full recommended dose of mineral fertilizer, PC_{10} + $RD_{1/2}$: 10 t/ha of pile compost + half of recommended dose, TC_{10} + $RD_{1/2}$: 10 t/ha of trench compost + half of recommended dose, PC_{10} + $RD_{1/4}$: 10 t/ha of pile compost + quarter of recommended dose, TC_{10} + $RD_{1/4}$: 10 t/ha of trench compost + quarter of recommended dose.

control plot. Soil total-N content were significantly (P < 0.01) increase 1.6 to 1.8 times in TC_{20}, PC_{20} and PC_{10} + $RD_{1/2}$ respectively compared with the control, whereas treatments TC_{10} + $RD_{1/2}$, PC_{10} + $RD_{1/4}$, TC10 + RD1/4 showed similar effect. The soil total-P supply of treatments PC_{20}, PC10+ RD1/4 and TC10 + RD1/4 was 3.7, 4 and 3.5 times significantly higher (P < 0.001) respectively compared with the control plot and 2.4, 2.6 and 2.3 times respectively with the RD. A significant (P < 0.001) increase of soil available P of 2.2 to 5.1 times and of 0.7 to 1.6 times compared respectively with the control and recommended mineral fertilizer dose (RD).The supply of treatments PC_{10} + $RD_{1/2}$, TC_{20}, TC_{10} + $RD_{1/2}$ and PC_{10} + $RD_{1/4}$ have had significantly (P < 0.001) improved soil exchangeable K compared with the control plot. It has contributed to an increase of 3.3; 2.2; 6.6 and 2 times of K respectively compared with the control plot, whereas treatments RD and TC_{10} + $RD_{1/4}$ showed similar effect with control.

Plant growth, yield and yield components

The plant height, number of leaves and leaf area index are presented in table 3. There were highly significant differences among the values of these parameters. Plant heights for PC_{20}, PC_{10} + $RD_{1/2}$, TC_{20} and TC_{10} + $RD_{1/2}$ were similar and significantly (P < 0.001) taller than the

Table 3. The influence of the conjunctive use of Municipal solid waste compost and mineral fertilizer on growth and morphological characters of maize at flowering stage

Treatments	Plant height (cm)	No. leaves/plant	LAI
Control	77.9a	9.0ab	1.1a
RD	116.9c	10.2bc	1.5b
PC_{20}	112.7c	10.0bc	1.4b
TC_{20}	121.8c	10.2bc	1.6bc
PC_{10} + $RD_{1/2}$	113.7c	10.9c	1.9bc
TC_{10} + $RD_{1/2}$	126.1c	10.4bc	2.2c
PC_{10} + $RD_{1/4}$	96.0ab	9.1ab	1.6bc
TC_{10} + $RD_{1/4}$	97.1ab	8.2a	1.8bc

Means with the same letter within a column are not significantly different using Tukey's test (HSD) at ($P \leq 0.05$); PC_{20}: 20 t/ha of pile compost; TC_{20}: 20 t/ha of trench compost; RD: Full recommended dose of mineral fertilizer, PC_{10} + $RD_{1/2}$: 10 t/ha of pile compost + half of recommended dose, TC_{10} + $RD_{1/2}$: 10 t/ha of trench compost + half of recommended dose, PC_{10} + $RD_{1/4}$: 10 t/ha of pile compost + quarter of recommended dose, TC_{10} + $RD_{1/4}$: 10 t/ha of trench compost + quarter of recommended dose.

Table 4. Maize production characteristics as affected by conjunctive use of Municipal solid waste compost and Mineral fertilizer

Treatments	Cob length(cm)	Cob diameter (cm)	100-grain weight (g)	Stover yield(kg/ha)	Grain yield (kg/ha)	Harvest index (%)
Control	8.4a	10.7a	23.4	1750a	950a	35.2a
RD	16.4d	17.4d	26.7	3270b	2430b	42.6b
PC_{20}	12.6c	13.4b	33.3	3800b	2400b	38.7ab
TC_{20}	16.0d	17.3d	33.4	4796c	3510c	42.3b
PC_{10} + $RD_{1/2}$	10.9b	12.5b	30.0	4260c	3170bc	42.7b
TC_{10} + $RD_{1/2}$	18.9e	20.3e	33.5	4800c	3960c	45.2bc
PC_{10} + $RD_{1/4}$	11.9bc	12.5b	30.0	3900bc	2760b	41.4b
TC_{10} + $RD_{1/4}$	13.1c	14.6c	25.0	4400c	3180bc	42.0b

Means with the same letter within a column are not significantly different using Tukey's test (HSD) at ($P \leq 0.05$); PC_{20}: 20 t/ha of pile compost; TC_{20}: 20 t/ha of trench compost; RD: Full recommended dose of mineral fertilizer, PC_{10} + $RD_{1/2}$: 10 t/ha of pile compost + half of recommended dose, TC_{10} + $RD_{1/2}$: 10 t/ha of trench compost + half of recommended dose, PC_{10} + $RD_{1/4}$: 10 t/ha of pile compost + quarter of recommended dose, TC_{10} + $RD_{1/4}$: 10 t/ha of trench compost + quarter of recommended dose.

control. The results clearly demonstrate that the number of leaves was significantly increased by conjunctive use of half dose of compost and mineral fertilizer (PC_{10} + $RD_{1/2}$ and TC_{10} + $RD_{1/2}$) over the control, whereas differences among the rest of the treatments were insignificant or slightly significant. Different treatments had significant effect on LAI ($P < 0.001$). Maximum LAI was observed with TC_{10} + $RD_{1/2}$ followed by PC_{10} + $RD_{1/2}$ and TC_{10} + $RD_{1/4}$. The highest leaf area index of 2.2 was observed with the TC_{10} + $RD_{1/2}$ treatment, whereas a leaf area index of only 1.1 was obtained in the control. Yield and its components are presented in Table 4. Treatment effects on cob length and cob diameter were significant, with the treatment receiving conjunctive application of TC and mineral fertilizer at 50 % (TC10 + RD1/2) giving the highest values (18.9 and 20.3 cm respectively), whereas the control treatment showed the lowest values (8.4 and 10.7 cm respectively). The 100-grain weight increased for the treatments where the composts were applied, compared with the control plot, but no significance was

Table 5. Macronutrient uptake (kg.ha^{-1}) in maize grain as affected by conjunctive use of Municipal solid waste compost and mineral fertilizer

Treatments	N	P	K	Ca	Mg
Control	11.1a	0.7b	3.3a	0.2a	0.8a
RD	33.7b	0.8b	7.3b	0.4b	2.1c
PC_{20}	32.3b	0.9b	7.4b	0.3b	1.8b
TC_{20}	64.1e	2.7e	12.5e	0.7f	3.0f
PC_{10} + $RD_{1/2}$	38.3c	0.9b	10.7d	0.5d	2.6d
TC_{10} + $RD_{1/2}$	63.9e	1.5d	12.3e	0.6e	3.8e
PC_{10} + $RD_{1/4}$	38.3c	0.8a	9.3c	0.4b	2.5d
TC_{10} + $RD_{1/4}$	59.1d	2.3c	9.3c	0.5c	2.3c

Means with the same letter within a column are not significantly different using Tukey's test (HSD) at ($P \leq 0.05$); PC_{20}: 20 t/ha of pile compost; TC_{20}: 20 t/ha of trench compost; RD: Full recommended dose of mineral fertilizer, PC_{10} + $RD_{1/2}$: 10 t/ha of pile compost + half of recommended dose, TC_{10} + $RD_{1/2}$: 10 t/ha of trench compost + half of recommended dose, PC_{10} + $RD_{1/4}$: 10 t/ha of pile compost + quarter of recommended dose, TC_{10} + $RD_{1/4}$: 10 t/ha of trench compost + quarter of recommended dose.

observed. The stover yield recorded was highest (3800 kg/ha) for plots treated with TC_{10} + $RD_{1/2}$, followed by TC_{20} (3796 kg/ha), TC10 + RD1/4 (3400 kg/ha) and RD (3270 kg/ha), whereas the lowest (1700 kg/ha) stover yield was obtained in the control. As individual applications, the 100% inorganic fertilizer (RD) treatment was similar to the organic source, but the combination of the two at half the dosage out yielded all other treatments. The grain yield closely followed the same pattern as that of the stover yield. In both cases, the positive interaction of TC in conjunction with mineral fertilizer applied at half the rate demonstrated a synergistic interaction between TC and mineral fertilizer on stover and grain production (tables 4). Overall, the treatments which received the composts improved significantly grain yield by 60 % (PC_{10}) to 76% (TC_5 + $RD_{1/2}$), compared to the control (950 kg/ha) treatment. Harvest index (HI) is the ratio of grain yield and total upper ground biomass which indicates the efficiency of plant to assimilate partition to the parts of economic yield (i.e. maize grain). Higher harvest index means plant capacity to deposit assimilates having economic importance specially grain in case of cereals. The statistical result revealed that the effect of treatments had significant differences on HI ($P < 0.001$).

Nutrient uptake and agronomic efficiency

Application of compost and chemical fertilizers in different combinations indicated a significant variation in nitrogen uptake by maize grain (table 5). The N uptake by maize grain ranged from 11.1 to 64.1 kg/ha. The highest N uptake was observed in the treatment TC20 with the application of trench compost at 20 t ha-1 and was statistically similar to the treatments TC10 + RD1/2 (10 t/ha of trench compost + half of recommended dose). The effects of the treatments RD and PC20 firstly, and PC10 + RD1/2 and PC10 + RD1/4 secondly on the N uptake by grain were statistically similar. The results indicated that compost when applied in combination with fertilizers increased the N uptake over the application of chemical fertilizers. The lowest value of N uptake by grain of 11.1 kg/ha was recorded in the control. Phosphorus uptake by maize grain increased significantly due to the application of compost and fertilizers (Table 5). The P uptake by maize grain ranged from 0.7 to 2.7 kg/ha and the highest P uptake (2.7 kg/ha) was observed in the treatment TC20. The second highest P uptake (2.3 kg/ha) was observed in the treatment TC10 + RD1/4. Application of full recommended chemical fertilizers (RD) exerted the statistically similar effect to the control, the treatments PC20 and PC10 + RD1/2 on the P uptake by maize grain. The lowest value of P uptake by grain of 0.7 kg/ha was recorded in the control.

A significant variation in the potassium uptake by grain was recorded due to the application of MSW compost and fertilizers (table 5). The K uptake by maize grain ranged from 3.3 to 12.5 kg/ha, and the highest K uptake was observed in the treatment TC20 which was statistically similar to the treatments TC10 + RD1/2. The treatment RD and PC20 in one hand and PC10 + RD1/4 and TC10 + RD1/4 in other hand were statistically identical in K uptake by maize grain. The lowest value of K uptake by grain of 3.3 kg/ha was recorded in the control.

The trend of variation of Calcium and Magnesium uptake by maize grain due to the application MSW

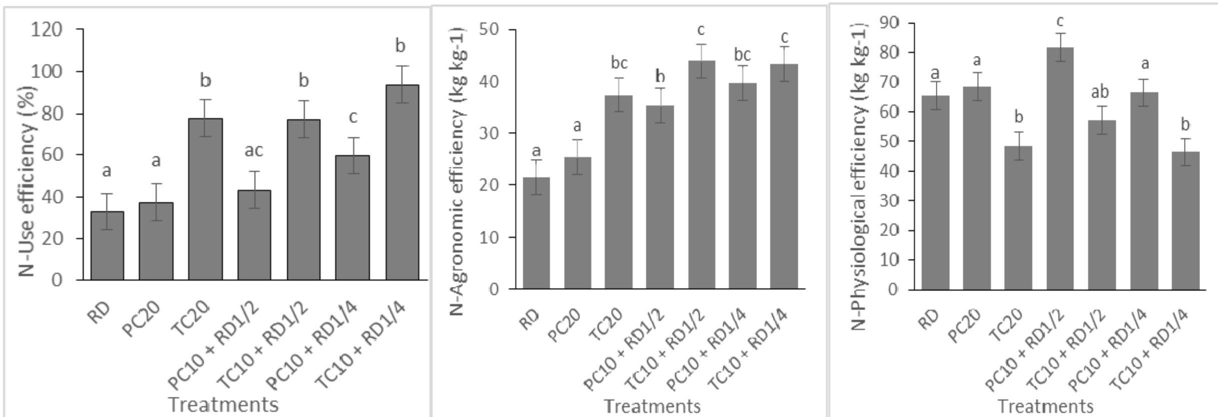

Figure 1. Efficiency parameters of N in maize grain as affected by conjunctive use of municipal waste composts and mineral fertilizer

PC_{20}: 20 t/ha of pile compost; TC_{20}: 20 t/ha of trench compost; RD: Full recommended dose of mineral fertilizer, PC_{10} + $RD_{1/2}$: 10 t/ha of pile compost + half of recommended dose, TC_{10} + $RD_{1/2}$: 10 t/ha of trench compost + half of recommended dose, PC_{10} + $RD_{1/4}$: 10 t/ha of pile compost + quarter of recommended dose, TC_{10} + $RD_{1/4}$: 10 t/ha of trench compost + quarter of recommended dose. Error bars represent the standard error of the mean. Columns with the same letter indicate values that were not significantly different at P = 0.05.

compost and fertilizers was approximately the same (Table 5). The Ca and Mg uptake ranged respectively from 0.2 to 0.7 kg/ha and from 0.8 to 3.8 kg/ha. The Ca and Mg uptake may be ranked as followed: TC10 + RD1/2 > TC20 > PC10 + RD1/2/ PC10 + RD1/4 > TC10 + RD1/4/RD > PC20 > Control.

The nitrogen use efficiency differed significantly between the treatments (figure 1). The highest values were obtained with TC_{10}+$RD_{1/4}$ (93.6%) followed by TC_{20} and TC_{10}+RD1/2 (77.6 and 77.2% respectively). For P, the highest value was obtained with TC_{20} + $RD_{1/2}$ (112.1 kg/kg) followed by TC_{20} (82.05 kg/kg). The lowest value of NUE of 33% was recorded in the RD treatment. As a result of the highest grain yields in compost-amended plots, agronomic efficiency (on a grain basis) of N was higher. The agronomic efficiency of N (AEN) was greatest in the treatment TC_{10} + $RD_{1/2}$ with a mean value of 44.0 kg grain kg^{-1} N applied, followed by 43.5 and 40.0 kg grain kg^{-1} N applied, in TC_{10} + $RD_{1/4}$ and PC_{10} + $RD_{1/4}$ treatments, respectively. Sole trench and pile compost at 20 t/ha (68.3 and 57.0 kg N ha^{-1} applied) showed higher agronomic efficiency than the sole mineral N application at approximately the same rate of N application (68.5 kg ha^{-1}). Physiological efficiency or internal grain N use-efficiency (kg grain kg^{-1} grain N uptake) indicated how efficiently maize produces grain relative to the N accumulated by the grain. Co-application of pile compost at 10 t/ha + half dose of mineral fertilizer recommended rate at 34.2 kg N ha^{-1} (PC_{10} + $RD_{1/2}$) had the greatest physiological efficiency (PEN) of 81.6 kg grain kg^{-1} N uptake, greater than that in the treatments PC_{20} (68.4 kg grain kg−1 N uptake), PC10 + RD1/4 (66.5 kg grain kg^{-1} N uptake) and RD (65.5 kg grain kg^{-1} N uptake). The lowest value of PEN of 46.4 kg grain kg^{-1} N uptake was recorded in the TC_{10} + $RD_{1/4}$ treatment followed by TC_{20} treatment (48.3 kg grain kg^{-1} N uptake).

DISCUSSION

Compost quality: pile versus trench compost

The loyally alkaline reaction of the composts is due to the high content of ammonia and cations (Ca, Mg and K) within the crop wastes (leaves and vegetable scrap, fruits), food wastes and animal wastes (egg shell, sheep and cow droppings residue) added to the organic materials. These results are in accordance with those obtained by Weber et al. (2007), showing that composts at maturity have pH around 7.3-8.0 which correspond to normal values for the organic fraction of municipal solid waste compost (Manios, 2004) and excludes all risk to the fertilization of the plants. The average value of the chemical characteristics of the composts showed that certain elements contained in the composts, such as organic element, azote, C/N and potassium, were in acceptable quantity. The values were higher compared to those of Compaoré and Naméma (2010) and Guene

(1995) respectively in Bobo-Dioulasso and in Ouagadougou and also comparable to those obtained by Waas (1996). The fertilizing value of these compost was based on the initial components of the wastes. The presence of vegetable wastes in the organic material could explain the high dose of carbon. Such characteristic of the studied composts would have the positive effect on the fertility status of the soil by releasing nutrient for the growing plant. The higher phosphorus and nitrogen contents in the trench compost comparatively to the pile compost could be attributed to the soil microbial activity in the presence of the animal wastes (egg shell, sheep and cow droppings residue) which is known to contain high N and P concentration. This can also due to loss of nutrient in the pile composting processing. According to Tittonell et al. (2010), open-air storage of manure, and thus exposure to rainfall and solar radiation favor loss of nutrients by volatilization and leaching. The average C : N ratios of 8 to 10 of the composts are quite favorable for soil microbiological processes (Busby et al., 2007) , as they do not create nitrogen hunger for the plants (Chaves et al., 2007; Tognetti et al., 2008) and it is a good indicator for the nitrogen mineralization (Sikora and Szmidt, 2001; Kowaljow and Mazzarino, 2007). In summary, from the different parameters studied, the compost produced in trench or pit presented good characteristics therefore, could be recommended to the small farmers for the improvement of the physical and chemical properties of the infertile soil, as they could contribute in an efficient way in the building up of soil organic matter.

Efficacy of the composts on soil fertility improvement

The seven pH of soil samples for the amended plots were not statistically different and ranged from 5.5 to 7.5, which is the optimum pH for maize growth (Lidon and Barreiro, 2002). The pH values were lower in the presowing than in the post-harvest soil samples. Soil pH is indicative of soil reaction and determines the availability and adsorption of soil nutrients by plant (Lyocks et al., 2013). The slightly increase in the pH of the soil after experiment is an indication that the application of organic materials on acid soils is beneficial and could reduce soil nutrient problems related to excessive acidity, common in the humid and subhumid environments. The effect of organic materials on soil pH was well known and documented. The high pH value was attributable to the low buffering capacity of soil due to its organic matter content and soil nature. The increase in pH of manure amended soil was also due mainly to the initial pH and the high content in basic cations of manure applied. According to Opala (2007) and Andric et al. (2012), the increase in soil pH after organic material addition is due to the high content in Ca and Mg of these materials. Indeed, the dissolution of organic material such as manure, compost, lime, etc. release basic cations particularly Ca and Mg which increase the base saturation of the soil solution and then increase pH.

Analysis of the data revealed that the effects of sole N sources and their combined effect in different proportion significantly improved the macronutrient status of the soil. Among sole N sources, maximum soil total N was recorded from the treatment of compost. Several studies reported soil nutrients increase after municipal waste compost is applied to soil comparatively to mineral N (Carbonell et al., 2011; Siddiqui et al., 2011). This is due in the fact that N from mineral source is soluble and can easily lost from soils through leaching and volatilization, which results in reduced fertilizer efficiency compared with organic N sources. According to Khalil et al. (2005) and Chen et al. (2008) organic N sources release nutrients slowly and contribute to the residual pool of organic N and P in the soil and reduce N leaching in soils. Among different ratios of compost and mineral fertilizer, relative highest total soil N was recorded in the treatments PC10 + RD1/2 (10 t/ha of pile compost + 50 % mineral N) and followed by the treatment TC10 + RD1/4 (10 t/ha of trench compost + 25 % mineral N). This might be attributed to the synergistic action played by the mineralization of organic matter and the residual effect of N sources which enhanced the N levels of the soil. It was supposed that the continued use of compost at 10 t/ha in conjunction with NPK at half or even quarter of the recommended concentrations can build up the fertility and significantly improve the N, P and K content of the soil. This practice may also help in reducing the loss of water quality caused by high leaching of nitrogenous fertilizers. Our results were supported by Melero et al. (2007), Courtney and Mullen (2008) and Mbau et al. (2014), who reported that application of compost increased soil macronutrients, especially C and N compared to inorganic fertilized plots and control. Amusan et al. (2011) concludes that the integrated use of legume residue, poultry manure and inorganic fertilizers increase the soil total N.

Organic matter and carbon were not significantly affected by sole compost, sole mineral fertilizer and their integrated effect. Nevertheless, the results revealed that trench compost as sole N source resulted highest soil organic carbon and matter and followed by the treatment TC10 + RD1/2 (10 t/ha of trench compost + 50% mineral N).This slight increase may be due to the dose of the applied compost, their initial organic matter content which vary depending on the source material, climate conditions, soil properties and the duration of this experiment. Similar results were also reported by (Carbonell et al., 2011) who observed in greenhouse experiment that the application rate of the MSW compost in soil at 50 t/ha led to an insignificant increase in organic matter content in soil, while the NPK fertilizer does not bring about any changes in organic matter content. Barral et al. (2009) underlined that the use of the MSW compost as an amendment in agricultural soils can be considered an option for conserving organic matter levels in soils. Several studies indicated that the increase in soil carbon can be observed only if the dose of organic manure is sufficiently high and is used for several years (Weber et al., 2014). According to these authors, larger amounts of organic matter result in a more substantial increase in organic carbon content.

In summary, the supply of combined waste composts and few amount of mineral fertilizer appears to be a suitable source of nutrient for crops in the ferruginous soil of Northern Benin and it has efficiently contributed in the building up of soil organic matter content, important component for soil texture improvement and soil biological activity.

Plant growth, yield and attributing characters

Based on the application rates used in this study, both the MSW compost and the NPK fertilizer significantly improved plant growth, yield (stover and grain) and yield attributes if compared to the control plot. Yield improvement under these treatments may be due to enhanced availability and use of N, water and other associated soil improving benefits from organic N sources. According to Crecchio et al. (2001); Herencia et al. (2007), Weber et al. (2007)), the addition of composted organic inputs to an agricultural soil increased the content of nutrients available for plants and some enzymatic activities directly associated to biochemical and microbiological transformations in soil. Also, Mbau et al. (2014) reported that soil macrofauna, especially earthworm, termites and beetles, were numerous on soil treated with composts compared to that of the control and inorganic fertilizer treatments. These beneficial changes in soil properties with compost-amended treatments, positively affect the growth and yield of maize. As this study, recent studies observed the beneficial effects of short-term supply of organic manures in maize (Masood et al., 2014).

Maximum plant growth and yield were recorded in the treatment TC10 + RD1/2 which was slightly or not different with the others combination and sole trench compost at 20 t/ha. The notable point here is that, plots treated with the full dose of mineral fertilizer had grain yields similar to that of the TC10 + RD1/4 plots (10 t/ha of trench compost + 25 % mineral fertilizer). The higher N and P content recorded in trench compost could have contributed to the difference seen in maize grain yields compared to other compost types. According to Khan (2008), this might be also due to increased photosynthetic activity in relation with adequate supplies of N and water from the different sources combined. Similar results were also reported by Soumaré et al (2003), Ayoola and Makinde (2007), Shah et al. (2009); Siddiqui et al. (2011), Amoah et al. (2012), Kaupa and Rao (2014) and Shahzad et al. (2015) who observed that the fertilizing potential of organic fertilizer is improved when it is applied with mineral fertilizer; the combined use of organic and inorganic N sources being an efficient approach to improve maize productivity compared to sole application of chemical fertilizer or organic manure. Mbau et al. (2014) reported higher maize grain yield on compost treated plots compared to those treated with mineral fertilizer. Although compost application rates were quite low with high quality than ours, their study emphasizes the superiority of composts in building soil nutrients reserves.

Then, it appears that the use of sole MSWC to supply crop nutrient requirement and optimum yields driven out to be an unappealing option in maize production, compared to combined application. Feasibly, short-term and rational conjunctive use of mineral fertilizer with the organic inputs such as municipal solid waste compost could start smallholder farmers on a trajectory to more yields.

Nutrient uptake and N-efficiency

Considering the effect of the treatments on plant chemical composition, a significant increase was observed in N, P and K content in the grain of maize plants treated with the combined application of MSW compost and mineral fertilizer. The macronutrient content in maize grain was similar in compost-amended plots to that from the NPK-fertilized plots. Higher concentrations of N, P and K in the maize grain were recorded in TC10 + RD1/2 and TC10 + RD1/4 treatments. Consequently, utilization of MSW composts to soil accompanied by supplementary fertilization with a mineral form of nitrogen appeared as a good alternative to conventional recommended NPK fertilization. Several studies have been reported that the use of compost, compost tea or bio-fertilizers has led to an increase in macronutrient content in the plant. This might be due to increased organic matter, N, P and K in soil and uptake of more soil nutrients by following fertilization with the trench compost. This increase might be also associated with the positive effect of compost and microorganisms in increasing the root surface area per unit of soil volume, water use efficiency and photosynthetic activity, which directly affect physiological processes. These results are supported by Siddiqui et al. (2011) and Nasir et al. (2010) who reported that organic manure such as MSWC are good soil conditioner and have the potential to increase N, P and K contents in different crops.

Nutrient use efficiency of N (NUEN) % values for maize crop varied significantly between treatments due to different N sources. Conjunctive application of mineral N with trench compost improved the NUEN than the sole application of pile compost or mineral fertilizer. This study showed overall, very high NUEN values for the maize crop in the integrated use treatments which could be due to the small dose of N used in these treatments. According to Sadras and Lamaire (2014), NUEN decline with increasing nitrogen rate.

N-Agronomic efficiency was affected by various mineral N and organic N and their combination. The maximum agronomic efficiencies of nitrogen were observed in the treatments TC10 + RD1/2, TC10 + RD1/4 and PC10 + RD1/4. These high values might be due to the fact that organic manures change in soil quality after manure addition are linked to the effects of organic matter content on soil structure and biological activity. Combination of organic manures with mineral fertilizers at small or sub-optimal doses was increasingly realized to improve the nutrient use efficiency and maize grain yield (Opala et al., 2010; Kamanga et al., 2013; Mucheru-muna et al., 2014) and could be a sustainable approach to enhance food security and environmental safety. Surprisingly, comparing the individual sources, the organic manures compete with recommended mineral fertilizer dose as the nutrients were easily available to the crops from the mineral source than the organic source. This finding was in contradiction with those of Kaupa and Rao (2014) who reported that sole use of poultry manure at 50 kg N ha^{-1} showed lower nitrogen agronomic efficiency than the sole use of mineral fertilizer at 50 kg ha^{-1} in sweet potato crop. The author underlined that the possible reason could be due to the increased supply of organic matter with lower potentially mineralizable N due to wider C: N ratio of poultry manure, thus resulting in lower availability of N to crop.

The co-application of pile compost at 10 t ha^{-1} + mineral fertilizer at 25 % of recommended rate had the highest physiological efficiency. The physiological efficiency was lower under sole use of trench compost at 20 t ha^{-1} than sole mineral fertilizer, which is in consonance with Kaupa and Rao (2014).

CONCLUSION

The aim of the present research work was to determine the fertilizing potential of municipal organic waste compost combined with mineral fertilizer, in order to evaluate its impact on soil properties, growth and the yield of maize. Our result showed that the combined use of municipal organic waste compost obtained with trench composting and mineral fertilizers at half the recommended dose produced maximum growth, resulted in higher grain and straw yield and increased the nutrient uptake. The co-application of municipal organic waste compost and inorganic fertilizer not only increased the availability of nutrients but also improved soil fertility and consequently enhanced maize grain production. Based on the nutritious needs of the growing of maize we can conclude that municipal waste compost can be an environmentally friendly solution to the disposal problem of these wastes and an adequate and sustainable low-cost strategy for the improving maize productivity in smallholder farming systems.

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