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Comparative effect of five compost types on growth and yield of maize (*Zea mays* L.) on a Ferric Acrisol in Ghana

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Abstract

The effect of compost application on maize (*Zea mays* L.) growth and yields was studied on a Ferric Acrisol in the semi-deciduous rainforest zone of Ghana. Five different composting formulations were done to assess their effect on growth and yields of maize. The compost materials consisting of municipal solid waste (MSW), Pig dung and Goat dung (feedstock-amendment ratios) were composted over a 12-weeks period under mesophilic (<50 °C) and thermophilic (>50 °C) stages using windrow composting approach. The compost treatments were; T_1 (100% mesophilic stage), T_2 (100% thermophilic stage), T_3 (50% mesophilic and 50% thermophilic stage), T_4 (80% thermophilic stage) and T_5 (80% mesophilic stage). Plot size measuring 3 m × 4 m were demarcated. Improved maize (Obatanpa) was planted in April and September, 2020 at spacing of 80 cm × 40 cm. Compost recommended application rates of 5 t/ha of each compost treatment were applied to the experimental plots two weeks after planting with three replications in a randomized complete block design. Compost treatment two (T_2) significantly ($p \leq 0.05$) recorded the highest N, at the end of the composting period. Results showed that compost treatment two (T_2) treated plots significantly ($p \leq 0.05$) recorded the highest grain yields of 4.4 t/ha and 3.62 t/ha during the major and minor cropping season. These findings suggest that, compost treatment two (T_2: 100% thermophilic stage) composting approach had short-term effects on nutrient supply, can be used by smallholder farmers to address soil fertility decline, improve nutrient availability and enhanced growth and yields of maize.

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Introduction

Waste management poses a great challenge to many nations including Ghana. The primary purpose of solid waste management is to promote good health, environmental protection, aesthetic, land use and economics associated with improper solid waste management (Tchobanoglous, 2003). Biodegradable waste generation in Ghana was 0.318 kg/person/day, forming 61% of the solid waste stream (Miezah *et al.*, 2015) and this fraction is increasingly becoming a major source of environmental pollution especially in urban areas (Fobil *et al.*, 2008). Apart from methods such as recycling, reduction at source, landfill and incineration, composting presents a tactic for reducing high volumes of organic waste in environmentally sound and desirable approaches (Ahmed *et al.*, 2007). Composting converts the active organic portion in solid waste into a stabilized product, which can be used as nutrient source for plant growth and as a conditioner to improve soil properties (Haung *et al.*, 2006). Smallholder farmers in Africa recognize the important role of compost in maintaining soil fertility (Onduru *et al.*, 2008). However, there are soil fertility problems in Ghana and most smallholder farmers cannot buy inorganic fertilizers for use because it is expensive (Ewusi-Mensah, 2009). The biodegradable waste generated, if composted, can contribute to soil fertility depending on its quality. Split addition of an N-rich substrate has been suggested as a way of reducing N losses from composting (Bryndum, 2014; Dresbøll and Thorup-Kristensen, 2005). During split addition of an N-rich substrate, the first part is added at the beginning of composting when compost temperature is < 50 °C (mesophilic stage) in order to support the turnover of carbon (C) and the remaining part is then added later at thermophilic stage when temperature is >50 °C in order to increase the N concentration in the compost (Luo *et al.*, 2014). These additions of different ratios of nitrogen-rich materials at mesophilic and thermophilic stages influence the composting temperature (Santos *et al.*, 2016) and nitrogen (N) transformations such as mineralization and volatilization (Chowdhury *et al.*, 2014). One challenge of adding these N-rich substrate for composting is the significant amount of nitrogen loss. There is therefore the need to link this effect by adding different ratios of nitrogen-rich materials at mesophilic and thermophilic temperature stages to amend the compost quality. However, it is not known how the timing of the addition of an N-rich substrate affects N losses under different optimal ratios of the addition of n-rich materials at mesophilic and thermophilic stages of composting. This study would help establish the right timing for adding the nutrient-rich substrates in order to get the desired compost quality and reduce environmental challenges encountered during the enrichment process. However, the timing and the optimal mixing rate of N-rich substrate as an additive at mesophilic and thermophilic stages is sparse. Organic amendment processes which is not cost-effective, retains nitrogen, and suitable agronomic properties from composting are more desirable. Therefore, this study sought to assess the effect of sole application of different composting formulations approach on growth and yields of maize for food security.

Materials and methods

Description of experimental site

The study was conducted at the experimental field of the CSIR- Soil Research Institute (06° 40′34.5" N, 001° 40′21.4" W), in the Kwadaso Municipality of the Ashanti Region of Ghana.

Compost preparation

Five main compost types were prepared according to the following ratio combinations; 4:2:1 compost (4 parts of biodegradable solid waste; 80 kg: 2 parts of pig dung; 40 kg: 1 part of goat dung; 20 kg) (Table 1). The weights of biodegradable solid waste, goat dung, and pig dung used were taken on a fresh weight basis. The goat and pig dung used for composting were obtained from goat pens and pig farms within the municipality.

Table 1. Treatment of compost formulations at mesophilic and thermophilic stages

Treatments	Composition
T1	All nitrogen-rich substrates (40 kg pig dung and 20 kg goat dung) were added to 80 kg biodegradable household waste at the start of composting (mesophilic stage) when compost temperature was < 50°C.
T2	All nitrogen-rich substrates (40 kg pig dung and 20 kg goat dung) were added to 80 kg biodegradable household waste at day 6 of composting (thermophilic stage) when temperature was > 50 °C.
T3	50% of nitrogen-rich substrate (20 kg pig dung and 10 kg goat dung) were added to 80 kg biodegradable household waste at the start of composting (mesophilic stage) when compost temperature was < 50°C and the remaining 50% were added at day 6 of composting (thermophilic stage) when temperature was > 50 °C.
T4	20% of nitrogen-rich substrate (8 kg of pig dung and 4 kg of goat dung) were added to 80 kg biodegradable household waste at the start of composting (mesophilic stage) when compost temperature was < 50°and the remaining 80% (32 kg of pig dung and 16 kg of goat dung) were added at day 6 of composting (thermophilic stage) when temperature was > 50 °C.
T5	80% of nitrogen-rich substrate (32 kg of pig dung and 16 kg of goat dung) were added to 80 kg biodegradable household waste at the start of composting (mesophilic stage) when compost temperature was < 50° and the remaining 20% were added at day 6 of composting (thermophilic stage) when temperature was > 50 °C.

Composting processes

Composting was done by heaping materials for 12 weeks. To homogenize material degradation, compost heaps were turned every 4 weeks together with the addition of 10 L of water. Data on temperature, moisture, and pH were taken frequently. The temperature was measured using an industrial thermometer placed at the centre of the compost pile for 4 minutes. Readings were taken between 11:30 am to 12:30 pm daily for the period of composting. Moisture content and pH of the compost pile were by direct measurement of weight loss and glass electrode meter measurement, respectively. To ensure accuracy, each compost treatment was replicated three times.

Field preparation, compost application and planting of maize

The experimental field was manually cleared with cutlass and hoe after which the field layout was done. Plot size measuring 3m × 4m with 18 plots in total and 6 plots per replication were demarcated. Each replication (block) consisted of 6 treatments with an alley of 2 m between each replication. Improved maize (Obatanpa) was obtained from the Ministry of Food and Agriculture (MoFA), Ejisu. Planting was conducted in April and September, 2020 at three seeds per hole of about 5 cm deep at spacing of 80 x 40 cm inter and intra-row respectively. These were thinned to a single plant per hill, 14 days after planting. Compost treatments were incorporated in the soil by hill application two weeks after planting. Control plots did not receive compost applications. Compost application rates of 5 t/ha of each compost treatments were applied to the experimental plots with three replications in a randomized complete block design. Regular weeding of the field was carried out throughout the experimental period. Defiance 4.8% ME with the active ingredient emamectin benzoate was sprayed to control the effect of harmful pests on the maize plants.

Data collection procedure

Each plot had four rows of which two central rows consisting the net plot were used for data collection and analysis. The first and last rows of each plot was left to border effect. A sub-sample of eight (8) tagged plants were randomly taken from each plot and the rest discarded. Plant height (cm), stem girth (cm) and leaf area (cm^2) were measured at ninety days (90) after planting. Biomass yield (t/ha), 100 seed (grain) weight (g) and Grain yield (t/ha) were measured at maturity stage of hundred and five (105) days.

Plant height and leaf area were measured using a measuring tape and leaf area meter. The plant height was taken from the soil surface to the epical tip of the plant. The leaf area was estimated as its length multiplied by its maximum width multiplied by maize leaf calibration factor of 0.75 (Ellings, 2000).

The plant stem girth was measured using digital vernier calipers. Grains harvested were recorded by threshing the cob, enveloped and oven dried at 80 °C for 48 hours, weighed and readings used to determine grain yield. 100 grains, Plant biomass (cob, stem, leaves, husk) were randomly selected from each plot enveloped and oven dried at 80 °C for 48 hours and weighed. Three measurements of each of the parameters were taken and then averaged.

To assess the nutrient status of the soil before cropping, Initial composite soil samples were taken at a depth of 0–15 cm before the treatments were applied.

Physico-chemical and biological analysis

Three representative samples of each compost were taken, dried at room temperature and milled to pass through a 1 mm sieve and were used for laboratory analysis. Total macro nutrients (N, P, K, Ca, and Mg), total organic carbon, heavy metals (Cu, Zn, Cr, Pb, Ni and Hg), polyphenol, and lignin content, were analyzed. The biological analysis involved the identification of fungi and bacteria. Kjeldahl method was used for the determination of nitrogen (Motsara and Roy, 2008). The Gallenkamp flame analyzer was used for potassium determination while phosphorus was determined from the standard curve (Motsara and Roy, 2008). Calcium and magnesium were estimated using the treatments sample solution containing the calcium and magnesium ions which reacted with an excess of ethylene diaminetetraacetic acid (EDTA) procedure as reported by Anderson and Ingram (1998). Dry combustion method was used for the determination of organic carbon (Motsara and Roy 2008). The heavy metals (Cu, Zn, Cr, Pb, Ni, and Hg) were determined from the atomic absorption spectrophotometer (Cunningham and Berti, 1993). Polyphenol content was by the Folin - Denis method while Lignin content was determined by the acid detergent fiber method (Anderson and Ingram, 1998). Faecal coliforms were determined from the most probable number (MPN) as reported by Obiri-Danso *et al.* (2005). Bacteria and fungi were cultured at 37 °C for 24 hours for growth to occur. The colony-forming units were counted using a Quebec colony counter and the procedure was repeated using cassava dextrose agar as a medium for fungi determination as reported by Ewusi-Mensah (2009).

Statistical analysis

GenStat software was used to run one-way analysis of variance for comparisons of all treatments at 5% significant level. TUKEY TEST was used to show exactly which treatments showed differences and exactly where the differences occurred. All graphs were drawn with Microsoft Excel.

Results

Initial conditions of composting materials used

The initial chemical properties of the three compost materials are presented in Table 2.

Table 2. Initial Chemical properties of compost materials

Properties	Household waste	Pig manure	Goat manure
Ph	6.56± 0.52	7.36± 0.28	7.86± 0.69
Moisture content (%)	18.68± 1.58	53.54± 2.11	22.37± 2.13
Organic C (%)	26.55± 1.9	35.06± 1.27	28.88± 2.8
Total N (%)	1.02± 0.19	2.17± 0.35	1.39± 0.26
Total P (%)	0.45± 0.08	2.15± 0.43	1.07± 0.08
Total K (%)	1.15± 0.13	0.47± 0.14	2.38± 0.41
Total Ca (%)	0.85± 0.11	5.59± 0.71	1.63± 0.12
Total Mg (%)	0.55± 0.1	1.91± 0.72	0.47± 0.06
C:N ratio	26.64± 5.25	16.44± 2.29	20.97± 1.86

NB: p = 0.0 5. Values are means of three replications

Results showed that, household waste was highest only in C:N ratio while pig dung had the highest moisture content, Organic carbon, Total N, P, Ca, and Mg. The chemical properties of the goat dung were generally between the pig manure (high) and household waste (low), except for Total K which was highest (2.38 + 0.41). Pig dung, therefore, is suitable as a nitrogen-rich substrate to compost household waste in producing compost for crop production. The analysis of variance at p = 0.05 showed that the chemical properties of the different compost materials were all significantly different from each other (Table 2). This implies that combining them would produce varying quality compost that could meet the nutrient needs of soil for sustainable crop production.

Chemical characteristics of matured compost used

The matured compost showed significant difference in electrical conductivity (EC) among the treatments except between T_1 and T_2 (Table 3). This shows that the differences existing from the ratios of the nitrogen-rich substrate has significant influence on the EC of a compost whether added at mesophilic or thermophilic stage. Precipitation of mineral salts and the production of metabolites such as ammonium generate these from the compost, especially the nitrogen-rich substrate (Valkili *et al.*, 2012). It was observed that all treatments had EC levels above the acceptable limit of 4 mS/cm, implying that they might be phytotoxic when used, could inhibit seed germination (Hargreaves *et al.*, 2008). However, Butler *et al.* (2001) observed that high EC value in composting may indicate the presence of nutrient.

The difference in macronutrients was generally not significant among the treatments, except, T_2 which had a significant ($p \leq 0.05$) increase in N content. The different ratios of the nitrogen-rich substrate had effect on the nutrients content. The variations in N contents among treatments in this study could be explained by the high temperatures, the long duration of the thermophilic phase. Therefore, it can be considered that temperature variation and maintenance during composting process directly affect the degradation process and microbial action on the materials (Singh and Kalamdhad, 2012). All NPK values for all treatments were within the acceptable range for quality of compost (Cortellini *et al.*, 2002; Straus *et al.*, 2003). C:N ratio in all the treatments were below the acceptable limit of 25:1 (Straus *et al.*, 2003), with T_2 recording the significant ($p > 0.05$) decrease in C:N ratio (Table 3).

Table 3. Chemical properties of matured compost

Parameter	Treatment				
	T1	T2	T3	T4	T5
Ph	7.93± 0.32^{a}	7.30± 0.1^{a}	7.77± 0.57^{a}	7.73± 0.4^{a}	7.57± 0.50^{a}
EC (mS/cm)	10.63± 0.1^{c}	10.56± 0.1^{c}	10.43± 0.08^{b}	10.85± 0.07^{d}	10.01± 0.11^{a}
Moisture (%)	37.97± 0.25^{a}	38.93± 0.21^{c}	38.23± 0.31^{ab}	38.83± 0.21^{bc}	40.00± 0.20^{d}
Organic C (%)	22.23± 0.3^{a}	22.20± 0.3^{a}	23.7± 0.75^{c}	20.8± 0.3^{a}	22.80 ± 0.3^{ab}
Total N (%)	1.19± 0.03^{a}	1.98± 0.04^{c}	1.29± 0.03^{ab}	1.30± 0.03^{a}	1.23± 0.06^{ab}
Total P (%)	0.88± 0.04^{ab}	0.97± 0.03^{b}	0.85± 0.04^{a}	0.85± 0.04^{a}	0.93± 0.02^{ab}
Total K (%)	2.09± 0.1^{ab}	2.45± 0.07^{b}	1.87± 0.12^{a}	1.71± 0.06^{a}	2.07± 0.12^{ab}
Total Ca (%)	1.13± 0.02^{ab}	1.35± 0.04^{c}	1.14± 0.02^{b}	1.23± 0.06^{bc}	1.00± 0.05^{a}
Total Mg (%)	0.68± 0.03^{ab}	0.74± 0.03^{b}	0.68± 0.02^{ab}	0.63± 0.03^{a}	0.65± 0.03^{a}
C:N ratio	18.68± 1.46^{ab}	11.21± 0.19^{c}	18.37± 0.14^{b}	16.01± 0.13^{b}	18.53± 0.55^{b}
Polyphenol (%)	1.58± 0.34^{a}	1.23± 0.21^{a}	1.43± 0.47^{a}	1.41± 0.23^{a}	1.48± 0.19^{a}
Lignin (%)	5.21± 0.3^{b}	4.44± 0.12^{ab}	4.72± 0.47^{a}	4.67± 0.11^{ab}	4.77± 0.5^{ab}

*Means with same superscript letter in a row are not significant different at 5% probability level (p = 0.05)

Li *et al.* (2013) revealed that sound composting reactions can also be expected when C:N ratios are also lower than 25:1. During the composting process, the C:N ratio of the initial feedstock declines. According to Chen *et al.* (2011), this decline occurs because each time organic compounds are consumed by micro-organisms, two-thirds of the carbon is given off as carbon dioxide. The study is also in agreement with Thambirajah *et al.* (1995) who reported that C:N ratio declined during the composting process because organic carbon is oxidised and the N mineralized by the micro-organisms. The lignin content decreased in all the treatments at the end of the composting process and this was because of the high temperatures especially in week 2. According to Toumela *et al.* (2000), the optimum temperature for mesophilic and thermophilic fungi involved in lignin degradation ranges from 40–60 °C. Assessed nutrients (Total Ca and Total Mg) in all treatments were at appreciable levels needed for agriculture application. According to Buechel (2018), Magnesium is necessary for chlorophyll production and nitrogen metabolism. Straus *et al.* (2003) indicated that Calcium (Ca) and Magnesium content in a matured should be within 1.5 - 7%.

Heavy metal concentrations

The level of heavy metals determined in each treatment is presented in Table 4. Generally, all the heavy metals in the treatments were lower than the recommended limit by Brinton (2000) probably due to the use of source separated household waste. There was no significant difference in concentrations of Cu and Hg in all the treatments. The highest observed Cu concentrations was in T_4 (15.57 ± 1.8 mg/kg) and that of Hg was in T_1 (0.3 ± 0.02 mg/kg). There was a significant difference in Cr concentration among T2 (15.13 ± 2.03), T3 (15.7 ± 2.23$^{)}$ and T_4 (17.83 ± 3.69$^{)}$, T_5(17.03 ± 0.6). The highest and lowest levels of Cr were in T_4 and T_2, respectively. The highest Cd was determined in T_4 and was significant different from all other treatments (Table 5). Pb was highest in T_5 (19.42 ± 0.98 mg/kg) and lowest in T4 (17.39 ± 2.12 mg/kg). There was significant difference in Pb only between T_4 and T_5. In the case of Ni, T_3 had the highest concentration (16.06 ± 3.33 mg/kg) and a significant difference existed between T_3 and T_5 as well as T_4 and T_5. The difference in Zn was significant between T_5 and T_1, T_2, T_3 with the highest obtained from T_5 (48.3 ± 2.37 mg/kg). Studies have shown that a lower heavy metal serve as essential micro-nutrients, yet they become harmful at higher concentrations (Dalcorso *et al.*, 2003).

Table 4. Heavy metals concentration in the matured compost

Heavy metal (mg kg^{-1})	Treatment					Heavy metals recommendation limits in compost	
	T1	T2	T3	T4	T5	Germany (mg kg^{-1})	USA (EU-range) (mg kg^{-1})
Cu	13.92 ± 1.55^{a}	14.71 ± 0.83^{a}	13.32 ± 0.69^{a}	15.57 ± 1.8^{a}	13.75 ± 1.07^{a}	3-20	70-600
Hg	0.3 ± 0.02^{a}	0.23 ± 0.04^{a}	0.24 ± 0.03^{a}	0.24 ± 0.03^{a}	0.23 ± 0.02^{a}	0.05-0.40	0.7-10
Cr	16.07 ± 0.49^{ab}	15.13 ± 2.03^{a}	15.7 ± 2.23^{a}	17.83 ± 3.69^{b}	17.03 ± 0.6^{b}	5-100	70-200
Cd	1.05 ± 0.2^{a}	1.06 ± 0.17^{a}	1.02 ± 0.18^{a}	1.11 ± 0.25^{b}	1.03 ± 0.2^{a}	0.3-7	0.7-10
Pb	19.15 ± 1.68^{b}	19.35 ± 5.34^{b}	18.87 ± 2.94^{ab}	17.39 ± 2.12^{a}	19.42 ± 0.98^{b}	12-100	70-1000
Ni	14.92 ± 0.5^{ab}	14.55 ± 0.98^{ab}	16.06 ± 3.33^{b}	15.92 ± 4.81^{b}	12.81 ± 2.19^{a}	4-50	20-200
Zn	45.74 ± 2.68^{a}	44.76 ± 2.65^{a}	44.68 ± 3.47^{a}	46.49 ± 2.29^{ab}	48.3 ± 2.37^{b}	14-125	210-400

*Means with same superscript letter in a row are not significantly different at 5% probability level (p = 0.05)

Microorganisms and their load

The levels of indicator organisms such as coliform bacteria allow predictions on concentrations of other pathogens because they are simple, safer to detect as well as generally occurring at higher levels (Takyi-Lartey, 2015). Also, they indicate sanitary quality of composts (Kalamdhad *et al.*, 2009). All treatments at the end of composting had faecal coliform below 5.0×10^2 MPN/g, which are the recommended fecal coliform densities for compost quality (Vuorinen and Saharinen, 1997).

The microbial biomass in the composted materials showed a higher level of bacteria in treatment, which had N-rich substrates added at the thermophilic stage (T_2 and T_4). This is due to the short duration of the thermophilic stage after the addition (Table 5). Thus, to ensure efficient pathogen inactivity, maintaining a minimum temperature of 50 °C or greater during the composting period is recommended.

Fungi have been reported to be an important group and are considered to play a very significant role in biodegradation and conversion of complex materials into simpler form during composting. Fungal diversity is reported to utilize many carbon sources of lignocellulosic polymers and are mainly responsible for compost maturation (Miller, 1996). Temperature has adverse effect on the growth of fungi, as they are eliminated by higher temperature and recover during the maturation phase when the temperature is moderate. Fungi were highest under the same N-rich substrate added at both mesophilic and thermophilic stages (T_3) and showed significant difference between T_1, T_3, T_4 and T_5 (Table 5). Most fungi are mesophilic tolerating an optimum temperature of 25 - 45 °C. However, at temperature of 55 °C during the early stages of thermophilic composting, fungal growth is significantly limited (Tiquia *et al.,* 2001). Dix and Webster (1995) indicated that fungi require optimum level of nitrogen for their growth as fungi were observed in all treatments after composting. Furthermore, fungi can survive at high temperature as spores and start to increase soon after the decline of thermophilic phase. This study detected low fungi during the initial stages of composting due to dominance of bacteria and had high proliferation soon after thermophilic phase same as has been reported by Ryckeboer *et al.* (2003).

Table 5. Bacteria, fungi, and feacal coliform in the matured compost

Treatment	Bacteria (x10^{5}CFU/g)	Fungi (x10^{5}CFU/g)	Feacal coliform (MPN/g)
T1	32.77 ± 2.81^{ab}	15.23 ± 4.4^{b}	426.7 ± 141.9^{bc}
T2	35.4 ± 2.63^{b}	14.2 ± 3.78^{ab}	460 ± 36.06^{c}
T3	32.37 ± 5.37^{ab}	15.33 ± 3.18^{b}	390 ± 69.28^{b}
T4	32.9 ± 1.4^{ab}	15.16 ± 4.78^{b}	326.7 ± 64.29^{a}
T5	30.5 ± 5.95^{a}	13.33 ± 5.26^{a}	390 ± 65.57^{b}

*Means with same superscript letter in a column are not significant different at 5% probability level (p = 0.05)

Effect of compost on maize yield

Physicochemical properties of soil of the experimental field

Table 6 shows data on the physicochemical properties. The results indicated that the soil was moderate in phosphorus but low in total nitrogen and bulk density (CSIR – Soil Research Institute, 1980). Exchangeable potassium, calcium and magnesium of the soil were adequate for maize production. The soil was moderately acidic and predominantly sandy loam.

Table 6. Physicochemical properties of Kumasi soil series (Ferric Acrisol) before trial establishment

Soil parameter	Value
Ph	5.81
Organic C (%)	1.23
Total N (%)	0.1
Available P (mg kg^{-1})	9.64
Exchangeable bases (cmolkg^{-1})	
K(K$^+$)	0.12
Ca (Ca^{2+})	4.23
Mg (Mg^{2+})	3.47
Total exchangeable bases (cmolkg^{-1})	7.82
Bulk density (gcm^{-3})	1.54
Sand (%)	70.44
Silt (%)	23.78
Clay (%)	5.78
Texture	Sandy loam

Growth parameter of maize

Plant height of all treatments were significantly ($p \leq 0.05$) greater than the control. The tallest and shortest plants at maturity were recorded by organic treatment two (T_2) with a mean of 155.7 cm and the control with a mean of 136.0 cm respectively (Table 7). Plant heights obtained from the study were significantly different from each other. Plant height ranged from 155.7 cm – 30.27 cm. Stem girth ranged from 5.50 cm to 1.40 cm among treatments (Table 8). There were significant differences ($p \leq 0.05$) in stem girth among treatments. Organic treatment two (T_2) had the highest stem girth value of 5.50 cm while the control recorded the least value of 3.00 cm at maturity. There were significant differences ($p \leq 0.05$) in leaf area among treatments. Leaf area ranged from 163.3 cm^2 – 42.37 cm^2 among treatments. Organic treatment two (T_2) recorded the highest leaf area value of 163.33 cm^2 whiles the control recorded the least leaf area value of 141.70 cm^2 at maturity (Table 9).

There was a significant difference ($p \leq 0.05$) in plant height among treatments (Table 7).

Table 7. Effect of compost on plant height (major and minor season, 2020)

Treatments	Plant height (cm)					
	Major season			Minor season		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T_1	65.67^{b}	137.3^{b}	166.0^{b}	51.33^{b}	124.0^{b}	142.0^{b}
T_2	79.33^{d}	149.7^{d}	175.7^{d}	65.33^{f}	137.0^{e}	155.7^{f}
T_3	73.00^{c}	143.0^{c}	171.4^{c}	58.00^{d}	130.0^{c}	148.0^{d}
T_4	77.33^{d}	147.3^{d}	174.1^{d}	61.67^{e}	135.0^{d}	151.7^{e}
T_5	70.67^{c}	141.0^{c}	167.4^{b}	55.67^{c}	128.0^{c}	146.7^{c}
Control	45.00^{a}	114.7^{a}	148.3^{a}	30.27^{a}	101.7^{a}	136.0^{a}
CV%	2.8	1.4	0.8	2.8	1.6	0.8

*Means with same letter in a row are not significantly different at 5% probability Level ($p = 0.05$), DAS: Days after sowing

Table 8. Effect of compost on stem girth (major and minor season, 2020)

Treatments	Stem girth (cm)					
	Major season			Minor season		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T1	2.90^{b}	4.26^{b}	7.10^{b}	1.96^{b}	3.23^{b}	3.50^{b}
T2	4.20^{f}	6.06^{d}	7.76^{e}	3.20^{f}	5.13^{e}	5.50^{e}
T3	3.40^{d}	5.06^{c}	7.36^{cd}	2.43^{d}	3.93^{c}	4.60^{cd}
T4	3.80^{e}	5.50^{c}	7.56^{de}	2.76^{e}	4.70^{d}	4.90^{d}
T5	3.20^{c}	4.45^{b}	7.16^{bc}	2.26^{c}	3.70^{c}	4.40^{c}
Control	2.40^{a}	3.46^{a}	5.90^{a}	1.40^{a}	2.66^{a}	3.00^{a}
CV%	2.3	5.3	1.9	3.1	3.9	5.0

*Means with same letter in a row are not significantly different at 5% probability Level ($p = 0.05$), DAS: Days after sowing.

Table 9. Effect of compost on leaf area of maize (major and minor season, 2020)

Treatments	Leaf area (cm^2)					
	Major season			Minor season		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
T1	58.23^{b}	138.0^{b}	181.6^{b}	45.27^{b}	127.1^{b}	154.0^{b}
T2	74.17^{f}	157.8^{f}	201.6^{f}	61.07^{f}	147.4^{f}	163.3^{d}
T3	67.20^{d}	148.5^{d}	193.8^{d}	54.23^{d}	137.4^{d}	159.0^{c}
T4	69.10^{e}	152.4^{e}	197.3^{e}	56.13^{e}	141.1^{e}	161.3^{cd}
T5	62.30^{c}	143.2^{c}	190.2^{c}	49.30^{c}	132.1^{c}	155.7^{b}
Control	55.30^{a}	133.0^{a}	175.2^{a}	42.37^{a}	122.1^{a}	141.7^{a}
CV%	0.1	0.1	0.1	0.3	0.5	1.1

*Means with same letter in a row are not significantly different at 5% probability level ($p = 0.05$), DAS: Days after sowing

Organic treatment two (T_2) recorded the highest plant height (175.70 cm) whiles the control recorded the least plant height (148.30 cm) at maturity. Table 8 shows the stem girth with a mean ranging from 7.70 cm to 2.40 cm among treatments. Organic treatment two (T_2) had the highest stem girth value of 7.77 cm whiles the control recorded the least value of 5.90 cm at maturity. Treatments showed a significant difference ($p \leq 0.05$) in stem girth and leaf area at maturity. Organic treatment two (T_2) recorded the highest leaf area value of 201.60 cm^2 whiles the control recorded the least leaf area value of 175.20 cm^2 (Table 9) at maturity.

Yield assessment of maize

The results of this study indicated that the highest and lowest hundred seed weight at maturity were recorded by organic treatment two (T_2) with the mean of 23.46 g and the control with the mean of 18.37 g (Table 10). There were no significant differences ($p > 0.05$) in hundred seed weight among treatments except organic treatment two (T_2) and the control. Grain yield ranged from 3.62

t/h to 1.11 t/h among treatments (Table 10). There were significant differences ($p \leq 0.05$) in grain yield among treatments. Organic treatment two (T_2) had the highest grain yield value of 3.62 t/h while the control recorded the least value of 1.11 t/h. There were significant differences ($p \leq 0.05$) in biomass yield among treatments. Biomass yield ranged from 7.82 t/h – 4.51 t/h. Organic treatment two (T_2) recorded the highest biomass yield value of 7.82 t/h whiles the control recorded the least biomass yield value of 4.51 t/h (Table 10) at the end of the study.

Table 10. Effect of compost on hundred seed weight, grain yield and biomass (major and minor season, 2020)

Treatments	Major season			Minor season		
	Hundred seed weight (g)	Grain yield (t/ha)	Biomass yield (t/ha)	Hundred seed weight (g)	Grain yield (t/ha)	Biomass yield (t/ha)
T1	23.55^{ab}	3.10^{b}	8.00^{a}	20.00^{ab}	2.207^{b}	5.477^{ab}
T2	27.26^{b}	4.41^{c}	9.87^{b}	23.46^{b}	3.623^{c}	7.820^{c}
T3	24.13^{ab}	3.15^{b}	8.13^{a}	20.56^{ab}	2.310^{b}	5.963^{ab}
T4	25.22^{ab}	3.24^{b}	8.38^{ab}	21.38^{ab}	2.427^{b}	6.263^{b}
T5	23.66^{ab}	3.09^{b}	8.03^{a}	20.15^{ab}	2.293^{b}	5.550^{ab}
Control	21.03^{a}	1.88^{a}	6.88^{a}	18.37^{a}	1.110^{a}	4.507^{a}
CV%	12.0	13.1	10.7	10.2	13.8	13.9

*Means with same letter in a row are not significantly different at 5% probability level ($p = 0.05$), DAS: Days after sowing

The results of this study indicated that the highest and lowest hundred seed weight at maturity were recorded by organic treatment two (T_2) with the mean of 27.26 g and the control with the mean of 21.03 g (Table 10). There were no significant differences ($p > 0.05$) in hundred seed weight among treatments except organic treatment two (T_2) and the control. Grain yield ranged from 4.41 t/h to 1.88 t/h among treatments (Table 10). There were significant differences ($p \leq 0.05$) in grain yield among treatments. Organic treatment two (T_2) had the highest grain yield value of 4.41 t/h whilst the control recorded the least value of 1.88 t/h. There were significant differences ($p \leq 0.05$) in biomass yield among treatments. Biomass yield ranged from 9.87 t/h – 6.88 t/h. Organic treatment two (T_2) recorded the highest biomass yield value of 9.87 t/h whiles the control recorded the least biomass yield value of 6.88 t/h (Table 10) at the end of the study.

Discussion

Effect of compost on plant height, stem girth and leaf area at maturity

Results from the study revealed that plant height, stem girth and leaf area had a positive association with the growth in maize. According to Haseeb ur Rehman *et al.* (2010), tall plants are likely to have more green areas for more photosynthetic activities that facilitate increase in plant growth. This phenomenon could be due to the fact that the taller the plant the more likely it is to have more leaves and which may result in greater chlorophyll content in leaves, hence the greater the chance for photosynthesis to occur leading to vegetative growth.

Results obtained during the major and minor cropping season of 2020 showed that application of compost performed significantly ($p \leq 0.05$) higher in plant height, stem girth and leaf area than the control under the two major seasons. This observation where the plant height, stem girth and leaf area increased significantly higher than the control plots is in agreement with Ayoola (2006) who reported that increase in crop growth were usually least in unfertilized/control plots because crops had to use the limited nutrients that the soil could supply without any external inputs. The increase in the nutrient status is attributable to the nutrient released of compost to the soil. This observation is in line with the findings by Curtis and Claassen (2005) and Farrell and Jones (2009) who reported that application of compost to soil improves soil fertility.

The highest plant height, stem girth and leaf area therefore obtained from compost at 100% thermophilic stage (T_2) which contained higher amounts of N, P and K contents suggesting that the maize plants benefited more from the faster released of NPK nutrients. In studies of Zarina *et al.* (2010) to investigate the effect of compost on growth and yield of maize, it was observed that treatments with the mixture of compost and inorganic fertilizers did significantly much better than those of sole inorganic fertilizers. It is therefore evident that compost boost the growth and yield of plants.

Effect of compost on biomass yield, grain yield, and hundred seed weight

Results obtained during the major and minor cropping seasons of 2020 showed that in all cases the application of compost was significantly ($p \le 0.05$) higher in increasing yields than the control. Biomass yield at harvest was higher in plots with higher nutrients released of compost compared to plots with lower nutrients released which might have increased the plant biomass at harvest. The result is in line with that of Bakht *et al.* (2006) who also found higher plant biomass at harvest with a higher dose of nitrogen application.

Compost at 100% thermophilic (T_2) treated plots gave the best yields during the two cropping seasons. There was a significant ($p \le 0.05$) increase in grain yield in the major and minor seasons of 2020 for all plots treated with compost except for the control plots. This observed phenomenon is explained in studies by Muller Saman and Kotschi (1994) who explained that during the first growing season only part (30 - 60%) of the manure becomes available and that the rest is fixed at first or is serving to build up the soil's humus and nutrient supplies.

The observed increase in these yield parameters could be linked to improved soil fertility, moisture content, adequate soil temperature, and reduced leaching of nutrients from the soil. The current results also confirm the work of Anon (2002) who reported that compost is an excellent fertilizer material because of its high nitrogen, phosphorous and potassium content and is readily available, improving the soil physical and chemical properties.

The results showed that Compost at 100% thermophilic (T_2) significantly ($p \le 0.05$) recorded the highest hundred seed weight than the control which recorded the least hundred seed weight. This increase in seed weight due to compost application could be related to improved soil fertility which in turn had increased the availability of the nutrients for improved plant growth and might be positively correlated with vigorous plant growth and thus might have increased the seed weight at harvest.

Conclusion

This study shows the best understanding of compost formulations under mesophilic and thermophilic stages and their effects on the growth and yields of maize for good management of the available organic resources. These findings suggest that, compost treatment two (T_2) significantly ($p \le 0.05$) recorded the highest N, at the end of the composting period. Results showed that organic treatment two (T_2) treated plots significantly ($p \le 0.05$) recorded the highest grain yields of 4.4 t/ha and 3.62 t/ha during the major and minor cropping season. These findings suggest that compost treatment two ($T_{2:}$ 100% thermophilic stage) composting approach can be used by smallholder farmers to address soil fertility decline, improve nutrient availability, and enhance growth and yields of maize.

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