Full Length Research Paper

Studies on the physico-chemical and microbiological parameters associated with composting of brewer's spent grains using different activators

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Seven compost piles were formulated using brewer's spent grains (BSG) as the bulk material amended with varied quantities of poultry droppings, soybean meal, cow dung and groundnut husks (activators). Composting was done through the static pile method in seven 30 × 25 cm containers. The process spanned 50 days during which temperature, pH, elemental profiles and microbial numbers were measured using standard procedures. Mature compost was pelletized with 22 mm extrusion pelletizer and applied to *Zea mays* in a randomized complete block design. The result showed 11.31% reduction in mean carbon content and 0.66% reduction in mean nitrogen content of composts at the end of composting. The most alkaline pH (10.66) and the highest temperature (55.7°C) were recorded in compost amended with poultry waste and soybean meal (BSGPS). Highest bacterial count in the first week of composting (5.8×10^7 cfu/g) was observed in compost pile amended with poultry waste alone (BSGP). Mean fungal counts were 2.0×10^3 cfu/g for compost pile amended with cow dung only (BSGC) and 5.0×10^3 cfu/g for the control compost pile (BSG). Composts from all seven piles had less than 10°C maximum rise in temperature over the ambient in Dewar self-heating assay and were deemed very mature. Pellets from BSGP and BSGPS compost showed 10% abrasion. Significant differences (p = 0.015) were observed in grain yield of compost-treated, NPK-treated, and untreated maize plants. The study concluded that compost made from brewer's spent grains mixed with poultry droppings and soybean meal in equal ratio increased grain yield of maize plant in proportions that competed favourably with that of NPK fertilizer.

Key words: Brewer's spent grain, compost, total microbial count, compost pellets, *Zea mays*.

INTRODUCTION

Human beings have been making organic fertilizers by biological decomposition of organic matter (usually wastes) for an inordinate length of time in an art com- monly referred to as composting (Lundin, 2007). Composting process consists of interactions between large number of diverse species of microbes in a very

Table 1. Constituents of Compost Piles (Factor Levels).

Pile number	Constituent	Ratio	Code
1	Brewer's Spent Grain + Poultry Droppings	1:1	BSGP
2	Brewer's Spent Grain + Poultry Droppings	2:1	2BSGP
3	Brewer's Spent Grain + Poultry Droppings + Soybean Meal	1:1:1	BSGPS
4	Brewer's Spent Grain + Cow Dung	1:1	BSGC
5	Brewer's Spent Grain + Cow Dung	2:1	2BSGC
6	Brewer's Spent Grain + Groundnut Husk	1:1	BSGGH
7	Brewer's Spent Grain Alone	Control	BSG

complex ecosystem (Szmidt, 1997).

Based on temperature organization, three distinct phases of composting are identifiable in a well mixed composting system (Neher et al., 2013). Initially, the temperature of the milieu prevails in compost pile but this soon rises significantly as degradation proceeds to herald the thermophilic phase. The thermophilic phase continues for a while after which temperature drops to the ambient when compost is almost stable (Stoffella and Kahn, 2001a)

Decomposition of organic carbon is carried out mainly by bacteria, fungi and actinomycetes; the organisms found during the composting process depend on the decomposition phase, properties of compost materials and temperature (Epstein, 1996; USDA, 2000). Bacteria are the key organisms responsible for degradation during active composting (Satyanarayana et al., 2012). When temperature exceeds 55°C and nears pasteurisation temperature, thermophilic bacteria have the largest population and pathogenic organisms are killed (Strom, 1985). The function of fungi in composting is not as pronounced as that of bacteria as most fungi are eliminated at temperatures higher than 60°C (Brock, 1978). The water content of compost is a key index of the composting process. Since microorganisms which are responsible for decomposition of compost materials require water as composite for their biomass. The optimum water level for composting has been set as 50 – 60% (Gershuny, 2011). Carbon loss by bio-oxidation during composting has been shown to range from 46 – 62% (Eghball et al., 1997) and nitrogen loss from 19 – 42% (Eghball et al., 1997); with low initial C:N (less than 1:26) being the basis for N loss (Tiquia et al., 2002; Ogunwande et al., 2008). Also, the contents of nutrients like potassium, magnesium, and iron in finished compost is usually higher than those of the compost raw materials (Stoffella and Kahn, 2001b; Smith et al., 2006; Alsup, 2008; Baharuddin et al., 2009).

Biomass densification means using some forms of mechanical pressure to reduce the volume of ground material to a solid form, which is easier to handle and store than original material (Erickson and Prior, 1990). A pellet is a small ball or piece of material that has been pressed tightly together.

The over use of inorganic fertilizers and intensive field-crop production can cause decline in the quality of agricultural soils. Compound fertilizer made by compost is ideal for soil application and peasants know that too much use of inorganic fertilizers is not good to the soil and the environment (Wei et al., 2000). Amoding et al. (2005) reported that maize yield significantly increased (p<0.05) with application of different soil amendments. Also, it has been documented that maize planted in composted manure-treated soils produced 12% greater above ground dry matter than did maize planted in fresh-manure-treated soils (Loecke et al., 2004).

This study was conducted to formulate compost piles with brewer's spent grain as the bulk material amended with varied quantities of activators, monitor changes in elemental composition pH and temperature of each treatment, examine the population and succession of microorganisms responsible for the composting process; and assess mechanical durability of pelletized compost and test agronomic impact of produced compost on maize cultivation.

MATERIALS AND METHODS

Collection of brewer's spent grains and activators

Fresh brewer's spent grains (the compost bulk material) were collected from International Breweries Limited, Ilesa, Nigeria. Poultry manure and cow dung were collected from Ogunsanya Farms, Iloko-Ijesa, Nigeria. Soybean meal and groundnut husk were collected from Johnson Olajide Fagboyegun Ideal Family Farms LTD, Owo, Nigeria.

Preparation of bulk material and formulation of piles

The bulk material was air-dried to achieve an approximate moisture content of 60% (Mongillo, 2000; Bajpai, 2011). Wood materials, glass chips, feathers and other foreign matter were removed from the activators. The materials were well mixed and put in 30 cm x 25 cm bins to obtain 7 static compost piles. The experiment followed a single factor layout: that is the only source of variation was in the constituent of each compost pile. Seven compost piles were formed and the details of each are given in Table 1.

Compost production from each pile

Composting proceeded for 50 days via the static pile method.

Turning was done mechanically at approximately 4 day interval during the first 35 days of composting to ensure constant aeration (Hao et al., 2001). Moisture amendment was carried out at approximately 8 day interval during the composting process.

Elemental analyses

Forty gram sample of compost from each pile were taken and air-dried. Air-dried samples were then used for analyses of C, Mg, N, P, K, Fe contents at the Department of Soil Science's Laboratory, Faculty of Agriculture, Obafemi Awolowo University, Ile-Ife, Nigeria.

Measurement of pH and temperature of amendments

The pH of compost samples was determined using standard procedures (MAFF, 1986). A sub-sample (5 g) of air-dried ground compost was transferred into a bottle and 25 ml of water was added. The bottles were capped and shaken mechanically at 200 revs per min for 15 min with a vortex mixer. The pH of the suspension was measured weekly using an electronic pH meter. The temperature of each pile was measured daily using a digital soil thermometer.

Enumeration of microbial count

Weekly samples of composts were taken and analyzed for microbial numbers according to Harley-Prescott's method (Prescott, 2002). The microbial groups enumerated were total viable mesophilic bacteria, fungi and actinomycetes.

Assessment of compost stability

Two tests were performed to assay stability of produced compost from each pile (Council, 2001). These were Dewar self-heating and germination index tests. The Dewar self-heating test was carried out by incubating compost samples in steel containers. Maximum–minimum thermometers were inserted 5 cm deep into each container. The containers were placed indoor with ambient temperature approximately 21°C for 7 days. The temperature of each compost sample was recorded daily. Maximum temperature rise of each pile over the test period were noted (Council, 2001). Germination index was measured by planting Soy bean seeds (five per 8 cm x 7 cm pot) in a blend of 50 percent compost and 50 percent soil. The mixture was hydrated with distilled water and placed in an environment with temperature of approximately 27°C. Emergence and growth were evaluated after 14 days and compared to growth of seeds in 100 percent soil (Council, 2001).

Pelletization and mechanical durability of pellets

Mature composts were converted into pellets by extrusion pelletization (Masayuki, 2001) at Ayo Best Feed Mill, Apete, Ibadan, Oyo State. The mechanical strength of pellets from each pile was determined by spinning 10 g pellet at 1000 rpm for 5 seconds in a centrifuge. The percent abrasion for each treatment was calculated as (Lowe, 2005):

$$A = M_F / M_I \times 100$$
$$M_F = M_I − M_P$$

Where, A = Abrasion (%); M_F = Fines (g), M_I = Initial weight (g); M_P = Pellet weight after test (g).
The lower the value of 'A' in the model, the stronger the pellets.

Agronomic evaluation

The effect of mature pelletized compost was investigated in situ on yellow, drought-resistant variety of Zea mays. A randomized complete block design (RCBD) was used with the following treatments; 1) BSGP compost + soil, 2) 2BSGP compost + soil, 3) BSGPS compost + soil, 4) BSGC compost + soil, 5) 2BSGC compost + soil, 6) BSGGH compost + soil, 7) BSG compost + soil, 8) NPK fertilizer + soil, and 9) soil alone. Each treatment was planted in plots measuring 3 m x 3 m with two replicates. Each treatment was applied at the rates of 1.1 tHa^{-1}. The materials were hand-applied, spread evenly and worked into the topsoil to a depth of 15-20 cm using a hand hoe. On maturity, plant heights were measured. Height was measured from the base of the stem to the youngest fully expanded leaf (Amoding et al., 2005). Grain yield was also measured as weight of grains per cob in grams.

Data analysis

Data derived from experimental procedures were subjected to statistical evaluation with SPSS 15.0 for descriptive and inferential statistics.
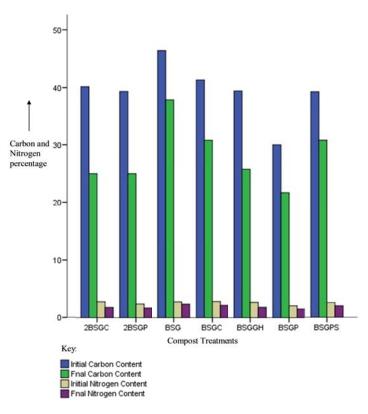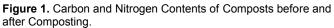
RESULTS AND DISCUSSION

Elemental composition of compost amendments

Initially, BSG had the highest carbon content of 46.41% while BSGP had the lowest being 30.03% (Figure 1). After composting, BSG still had the highest C content at 37.83% and BSGP still the lowest being 21.65%. The mean initial carbon content of the 7 treatments was 39.42%; this dropped to 28.11% after the composting period. Before composting, mean N content of piles was 2.57% and this dropped to 1.91% after composting. Quantitative reduction in mean carbon and nitrogen content could be attributed to microbial metabolism of carbon and volatilisation of nitrogen (Martins and Dewes, 1992) especially with a C:N lower than 26:1 in tandem with published literature (Smith et al., 2006).

Prior to composting, magnesium content peaked in the 2BSGP pile being 8.64 CMol/Kg and was lowest in the BSG pile being 2.01 CMol/Kg (Figure 2). Mean Mg content was 5.46 CMol/Kg before composting. After the composting period, BSGPS recorded the maximum Mg content being 9.2 CMol/Kg and BSGGH recorded the minimum being 4.26 CMol/Kg. Mean Mg content rose to 6.90 CMol/Kg. Mean K content rose from 4.61 CMol/Kg in the raw materials to 6.19 CMol/Kg in the finished compost (Figure 2).

Before composting, BSGPS pile had the highest phosphorus content of 387.03ppm and 2BSGP had the lowest of 240.56 ppm. Mean P content was 294.19 ppm. After maturation, BSGGH recorded the maximum P content being 836.84 ppm and mean P content rose to 669.17 ppm. Mean Fe content increased from 328.03 ppm in the raw materials to 668.69 ppm in the finished compost (Figure 3). The quantitative increase in potassium, magnesium, phosphorus and iron contents of mature compost is consistent with existing studies
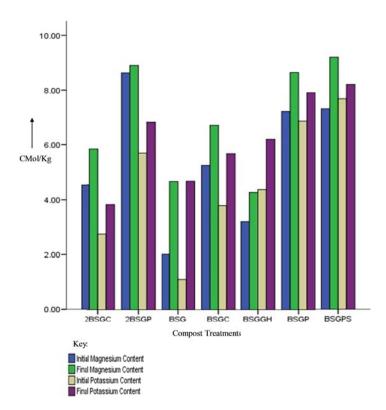
Figure 1. Carbon and Nitrogen Contents of Composts before and after Composting.

Figure 2. Magnesium and potassium contents of compost piles before and after composting.
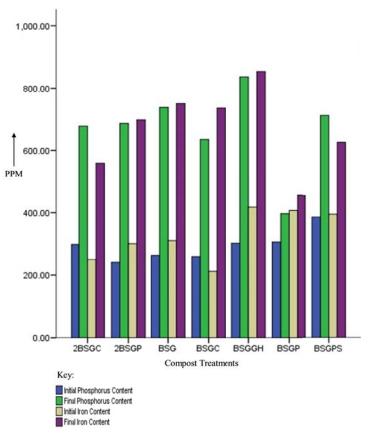
Figure 3. Phosphorus and iron contents of compost piles before and after composting.

(Stoffella and Kahn, 2001b; Smith et al., 2006; Alsup, 2008; Baharuddin et al., 2009) and could be attributed to reduction in bulk resulting in higher availability of the elements after composting.

pH and temperature profiles of compost piles

During the first 2 weeks of composting, the pH of all the compost piles increased steadily from neutral to alkaline. The BSGPS pile had the highest pH of 10.66 and BSGP had the lowest (7.23). As composts tended to maturity, pH values stabilized in the alkaline range and the lowest mean pH was 8.18 (BSGP). The relatively high mean pH range of 8.18 – 9.09 recorded may be attributed to the low C:N ratio of treatments resulting in conversion of nitrogen to ammonia. In the first 2 weeks of composting, there was marked increase in temperatures of all amen- dments. BSGPS reached the highest temperature of 55.7°C. The high temperatures of compost piles in the first 2 weeks of composting resulted from vigorous bacterial activity during this period. After the 3rd week of composting, temperature of the compost piles stabilized almost to the ambient temperature. The highest mean

temperature reached was 34.7°C (BSGPS) and the lowest was 23.9°C (BSGGH). The mean ambient temperature spanning the entire composting time (50 days) was 27.3°C (Figure 4).

Microbial population of amendments

Total viable mesophilic bacteria counts were high in the first week of composting in all piles. BSGP had the highest population in week 1 being 5.8×10^7 cfu/g. Bacterial numbers declined in week 2 to as low as 1.5×10^4 cfu/g in BSG. The maximum bacterial count, 6.0×10^7 cfu/g was recorded in the 3rd week in the 2BSGC pile. After week 3, bacterial numbers generally declined to as low as 1.0×10^4 cfu/g in BSGP in the 7th week. This may have been as a result of reduction in carbon available for metabolism. The highest mean bacterial count obtained was 1.1×10^7 cfu/g (2BSGC) and the lowest was 2.7×10^6 cfu/g in BSG (Figure 5).

Fungal populations also were high in the first 3 weeks of composting. BSGGH had the maximum fungal population in the first week being 6.0×10^4 cfu/g. Fungal species isolated in the first week included *Alternaria* spp,
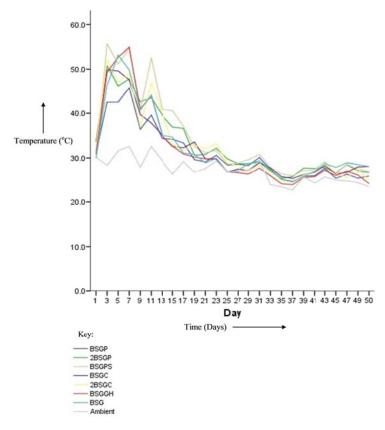
Figure 4. Temperature Profile of compost piles during composting.
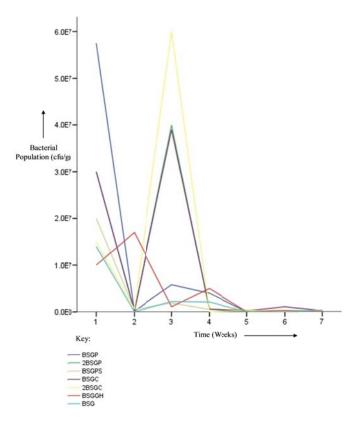

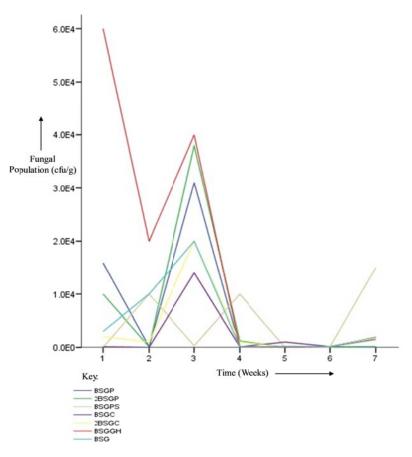**Figure 5.** Mesophilic bacteria population of compost piles.

Figure 6. Fungal population of compost piles.

Aspergillus spp, *Mucor* and *Rhizopus* spp. Spanning the entire period of composting, the mean fungal counts were 6.8×10^3 cfu/g for BSGP, 7.1×10^3 cfu/g for 2BSSGP, 5.1×10^3 cfu/g for BSGPS, 2.5×10^3 cfu/g for BSGC, 3.7×10^3 cfu/g for 2BSGC; 1.7×10^4 cfu/g and 5.0×10^3 cfu/g for BSGGH and BSG respectively (Figure 6).

Actinomycetes population were initially low in the first three weeks of composting with the highest during this period recorded in 2BSGP being 9.0×10^6 cfu/g (Figure 7). There was an increase however in actinomycetes population starting from week 4 thus: BSGP, 3.0×10^7 cfu/g; 2BSGP, 5.0×10^5 cfu/g; BSGPS, 6.0×10^4 cfu/g; BSGC, 3.0×10^6 cfu/g; 2BSGC,BSGGH and BSG, 2.0×10^5 cfu/g, 4.0×10^4 cfu/g and 4.0×10^5 cfu/g respectively. The increase in actinomycetes number after the 4th week may be due to lower competitive stress effected by lower bacterial and fungal counts. The pattern of compost colonization by actinomycetes in this study is consistent with that reported by Golueke et al. (1954) and Davis et al. (1992). BSGPS had the highest actinomycetes count of 5.6×10^7 cfu/g in the 7th week. The highest mean actinomycetes count of 1.0×10^7 cfu/g was recorded in BSGGH and the lowest, 1.3×10^6 cfu/g in BSG.

There was no significant differences (P=0.899) in microbial counts across treatment levels suggesting that substrate composition of compost piles is not a limiting factor to microbial numbers and succession during composting. Results of this study show that the presence of activators alongside carbon-rich bulk material however is a determinant of microbial population. This is supported by the fact that mean bacterial (2.7×10^6 cfu/g), mean fungal (5.0×10^3 cfu/g) and mean actinomycetes (1.3×10^6 cfu/g) counts were lowest in the control pile (devoid of activators) in this study and in a separate research that investigated the effects of activators during composting of threshed palm fruit bunches reported by Chukwudi (2011).

Compost stability indices

Dewar Self-Heating Test

Highest maximum temperature increases were observed in BSGGH (8.10°C), 2BSGC, BSGC, and BSGP composts (all 8.00°C). Compost samples from the three other piles (2BSGP, BSGPS, BSG) all had highest maximum temperatures of 7.00°C. All the compost piles were thus deemed very mature since they all had lower than 10°C as maximum temperature rise over ambient during the 7 day test period (Council, 2001).
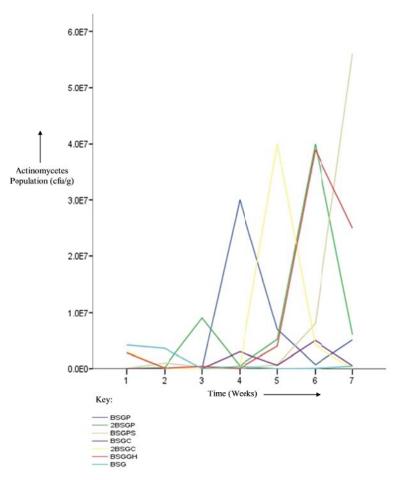
Figure 7. Actinomycetes population of compost piles.

Germination index

The two indexes measured in the germination test were Soybean plants' root and shoot length (RL and SL) in centimetres. The mean RL of the control plants was 1.10 cm and the mean shoot length was 4.90 cm. Mature compost must produce plants indexes (RL and SL) longer than 90 % of those of the control, soil only (Council, 2001). Plants in the compost pots 1-7 all had RL and SL longer than 0.99 cm (90 % of mean root length of control plants) and 4.90 cm (90 % of mean shoot length of control plants); hence all compost piles were deemed mature.

Compost stability indices obtained in this study were consistent with those reported in a separate investigation (Chukwudi, 2011).

Mechanical durability of compost pellets

Pellets made from BSGP and BSGPS had the least abrasion values being 10%, pellet made from BSGC had 15%, 2BSGC pellet had 18% while 2BSGP, BSGGH and BSG pellets had 20, 30 and 40% abrasion respectively.

Relatively low abrasion values of pellets containing poultry waste (BSGP, 2BSGP and BSGPS pellets) suggest better binding capacity of constituents. High abrasion value of the control (BSG only) suggests high friability of pellets. From these data it could be clarified that compost with higher percentage of organic nitrogen or with lower percentage of carbon is constituent form for better pellets.

Agronomic evaluation

Heights of Zea mays

The tallest plant was obtained from the 'NPK' plot being 221 cm. Plant height of 203 cm was recorded in BSG-treated plot while BSGPS treated plot recorded 200 cm tall. The least height was obtained in the 'Soil-only' control plot being 127 cm (Figure 8). Mean plant heights in BSGP, BSGC and BSGPS treated plots were higher than that of the control plot (Soil-only) by 46.18, 37.02, and 49.24 % respectively. Mean plant height of BSGPS treated plot was higher than that of NPK treated plot by 2.29%.
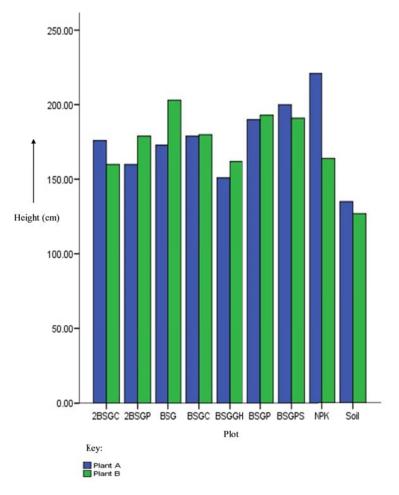
Figure 8. Effect of Soil Fertility Amendments on Maize Plant Height.

Yield of *Zea mays*

Figure 9 shows the grain yield of maize plants. Mean grain yield was highest in the BSGPS plot being 306 g. The mean grain yields of BSGP, 2BSGP, BSGPS, 2BSGC, and BSGGH treated plants was higher than that of untreated maize plants by of 15.88, 18.13, 37.25, 22.63, 21.00, and 29.88 g respectively. BSGPS treated plants exceeded the mean grain yield of NPK treated plants by 4.25 g. Post – hoc analysis (Tukey's honest significant difference) showed that significant differences existed ($p = 0.05$) in the effect of BSGPS and BSGGH amendments on grain yield over the control which compared favourably with the effect of NPK fertilizer over the control (soil only). This result is in concord with the findings of Amoding et al. (2005). The increase in plant height and grain yield in the BSGPS plants may be attributed to high contents of primary elements required for plant growth in BSGPS compost; with C:N being 15:1, Mg (9.2 CMol/kg), K (8.21 CMol/Kg) and P (387.03 ppm); in agreement with the postulations of Bender and Faber (2007).

CONCLUSIONS AND RECOMMENDATION

Brewer's spent grains can be used as a soil fertility amendment alongside items currently tagged as 'wastes' such as poultry droppings, soybean meal and groundnut husks (poultry waste mixed with soybean meal gave the best plant-yield results in this study). Results from this research have shown that in appropriate mixtures, these materials could be refined by microorganisms into agriculturally important soil conditioners. The product can be stably pelletized for improved storage, transportation and handling. The pelletized compost can compete favourably with commercially available inorganic fertilizers in terms of yield of staple crops like *Zea mays*.

Using brewer's spent grains in the production of organic fertilizers will help in reducing the waste currently generated in the brewing industry and also provide more affordable alternatives to inorganic fertilizers in wide contemporary farming application.

From the results of this study, poultry droppings and soybean meal mixed in equal ratio are recommended as activators for compost production from brewer's spent
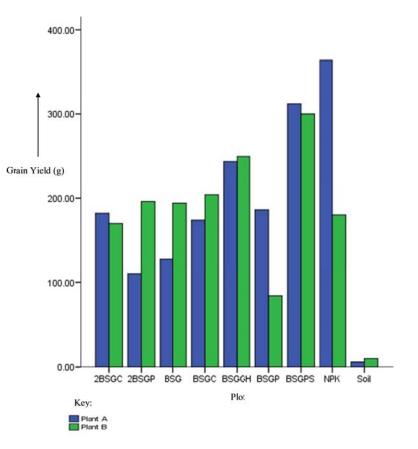
Figure 9. Effect of soil fertility amendments on maize grain yield per plant.

grains especially for the cultivation of *Zea mays.*

Conflict of interest

The author(s) have not declared any conflict of interests.

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