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Full Length Research Paper

Effect of heat build-up on carbon emissions in chimato compost piles

Angstone Noel J. Thembachako MLANGENI[1]*, Shaibu KANANJI[2] and Sosten S. CHIOTHA[3]

[1]NR Department, Natural Resources College, Box 143, Lilongwe, Malawi.
[2]Agriculture Department, Natural Resources College, Box 143, Lilongwe, Malawi.
[3]Biology Department, Chancellor College, University of Malawi

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A study was conducted to determine impacts of heat build-up of chimato compost piles TD0, TD20, TD40, TD50, TD60, TD80 and TD100, made by blending maize stalks with 0, 20, 40, 50, 60, 80 and 100% *Tithonia diversifolia*, respectively, on carbon losses and emissions during composting. Compost piles temperatures that determined heat built-up were obtained from previous studies. Organic carbon and total carbon of chimato composts were determined using Kjeldahl method. Relatively, greater carbon reductions were observed in compost piles TD0, TD20, and TD40 (that experienced prolonged high thermophilic temperatures (temperature >60°C)) than compost piles TD50 and TD60 (that experienced a short-lived thermophilic temperatures (45≤60°C)). The prolonged high temperatures increased kinetic energy of chemical species CO_2 and CH_4 that became more volatile and probably escaped from the compost piles in large quantities resulting in significant carbon emissions. Relatively, short-lived heat built-up in TD50 and TD60 resulted in minimal carbon reduction, hence minimal carbon emissions. Therefore, chimato composts TD50 and TD60 significantly reduce compost pile carbon emissions ($p=0.05$, $\alpha=0.001$) and should be recommended to mitigate effects of climate change.

Key words: *Tithonia diversifolia*, heat built-up, carbon emissions, carbon reduction, prolonged thermophilic temperatures.

INTRODUCTION

Agriculture sector plays vital role in sustaining growth and reducing poverty in many countries in Africa including Malawi. However, depletion of soil fertility as well as organic matter has been reported to continuously and negatively affect sustainable agricultural production in Malawi (Elias et al., 2013). Application of composts in agricultural filed has been identified as one of the potential initiative to replenish soil fertility and organic matter. It is reported that application of well matured and stable composts into agricultural fields significantly increases soil carbon content by diverting inorganic atmospheric carbon compounds such as dioxide (CO_2) and methane (CH_4) into soil organic carbon compounds (Biala, 2011; Gill et al., 2012; Biddlestone and Gray, 1987). Maturity and stability of compost is partly dependent on type of feedstock that influence compost pile moisture content, aeration and heat build up. Well matured and stable composts gradually decompose

*Corresponding author. E-mail: anjtmlangeni@yahoo.com. Tel: +265 8 8830 1288.

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under aerobic conditions (Biddlestone and Gray, 1987; Christensen and Peacock, 1998).Compost piles that mature into well matured and stable composts usually meet certain minimum blending composition of nitrogen rich ingredients and carbon rich ingredients (WSU, 2010; Mlangeni et al., 2013). Such requirements make ingredients to be digested very fast by microbes and the compost pile stays in high thermophilic stage for relatively short time (Mlangeni, 2013).

On the contrary, immature and unstable compost is usually produced when fewer quantities of nitrogen rich have been blended with disproportional large quantities of carbon rich feedstock. Such ingredient composition limits microbial activities. Microbes use limited available nitrogen to slowly digest ingredients in prolonged high thermophilic temperatures. The high temperatures ensure availability of microorganisms that multiply rapidly at specific temperature range (WSU, 2010). Therefore, compost piles that stay in the high thermophilic phases for a long time are symptomatic to prolonged exothermic oxidation reactions that built-up large amount of heat (WSU, 2010). Large generation of prolonged heat is attributed to high active microbial activities taking place in the compost piles due to quantities of high carbon content cellulosic materials (lignin) whose oxidation and digestion generate large amounts of heat (Agromisa, **1990**). The compost piles stay longer in the thermophilic stage because of greater quantities of hard to digest materials in the feedstock that prolongs maturity period. Thus, the compost piles' prolonged stay in the thermophilic stage may have a negative impact on kinetic energy of chemical species available in the compost pile, which may also be symptomatic to volatilization and consequently to loss of such chemical species.

Smallholder farmers in Malawi are encouraged to make and use chimato compost in their fields. However, such farmers use low quality ingredients such as grass and maize stalks. Use of nitrogen rich ingredients such as *Tithonia diversifolia* biomass is recommended (Mlangeni et al., 2013). Temperature progression of chimato compost piles made using 80 and 100% of *T. diversifolia* was reported to rapidly increase to high thermophilic peak temperature (54.5 and 55°C respectively) before rapidly dropping down to mesophilic phase (35.0°C) (Mlangeni, 2013). Temperature progression of chimato compost piles made using 60 and 50% of *T. diversifolia* was reported to experience prolonged stay in the high thermophilic phase peak temperature (65.0 and 70.0°C), respectively, symptomatic to well matured compost (Biddlestone and Gray, 1987; Biddlestone and Gray, 1987; Darlington, 2010). The blending is reported to generate a balanced heat build-up conducive to initiate a self-accelerated process of decomposing the feedstock (Mlangeni et al., 2013). Chimato compost piles' heat build-up determines both nitrogen and carbon content of the chimato composts. Too high temperatures deactivate mesophilic microbes whereas a longer duration of high temperatures accelerates losses of methane (CH4), carbon dioxide (CO_2) and nitrogen loss as ammonia NH_3 and nitrogen oxide through volatilization (Carr, 1998; CAW, 2012). Heat built-up in compost pile is dependent on quality of ingredients used in constructing the compost piles (Mlangeni, 2013), whereas quantity of CO_2, methane and other nitrides diverted is dependent on type, stability and quality of composts. High quality ingredients such as *T. diversifolia* enhances rapid and active microbial activity that break down chemical bonds of compounds and transforms chemical energy (Biddlestone and Gray, 1987; WSU, 2010) contained in the bonds to heat, which raises the temperature of the compost pile (Mlangeni, 2013). Blending maize stalks with *T. diversifolia* of greater than 40% ensures availability of both carbon and nitrogen in sufficient amounts to enhance optimal active and rapid microbial activities. It is suggested that optimal heat build-up may have significant impacts on residual compost nitrogen and carbon. This study was conducted to determine impacts of compost piles heat build-up of chimato compost produced by blending maize stalks with different quantities of *T. diversifolia* on carbon losses and carbon emissions during composting.

MATERIALS AND METHODS

Study site

The study was carried out at Natural Resource College farm (130 85' S 330 38, E) in Lilongwe, Malawi. Natural Resource College farm is about 13 km south west of Lilongwe town and 3.5 km off Lilongwe-Mchinji road. It lies on an altitude of 1146 m above sea level. Natural Resource College experiences mean annual temperature of 20°C and mean annual relative humidity of 68%. It receives an annual mean rainfall of 892 mm of which 85% falls between November and March (DARETS, 2002).

Experimental design and treatments

Six standard chimato composting treatments Td0, Td20, Td40, Td50, Td60, Td80 and Td100 were made. In each case, *T. diversifolia* biomass was blended with maize stalks in the ratio (TD/MS) 0:100, 20:80, 40:60, 50:50, 60:0, 80:20 and 100:0 respectively by mass. Tender green *T. diversifolia* shrubs of about 8 weeks old (counted from the date the *T. diversifolia* shrubs were slashed for regeneration) were used. Both maize stocks and the *T. diversifolia* materials were cut into pieces ranging from 5.0 to 10.0 cm. The small sizes were chosen to increase surface area onto which microbes would act on, to enhance efficient diffusion of air throughout the entire pile and to enhance active and rapid aerobic decomposition (Nalivata, 2008; Michel et al, 2010). Each compost pile was adequately watered to optimize compost pile moisture content. Initial diameter of each compost pile was 1.5 m wide, 1.5 m high and conical shape. The piles were then plastered on the outside with mud as shown in Figure 1. Air vents (Figure 1c) were made at the bottom and middle of the piles to allow air circulate through the biomass to enhance aerobic degradation (Nalivata, 2008).

Figure 1. a) Un-plastered compost pile; **b)** freshly plastered conical piles; **c)** matured chimato compost piles.

Analysis of chimato composts

Compost samples were purposely collected from different locations of the matured chimato compost pile. Samples from each treatment were homogeneously mixed to get a composite representative sample. The samples were analyzed for total Kjeldahl carbon and organic carbon using Kjeldahl method (Jeffery et al., 1989).

Data analysis

Data was analyzed using SPSS 17.5 version. Level of variation of organic carbon and total Kjeldahl carbon were determined using analysis of various (ANOVA).

RESULTS AND DISCUSSION

Effect of prolonged stay in high thermophilic phase on carbon losses

Study results indicates that amounts of carbon losses in chimato compost TD0 and TD20 were significantly different from carbon losses of chimato composts TD50, TD60, TD80 and TD100 ($p=0.018$; $\alpha=0.05$; Wilcoxon). Carbon losses in TD0 was not significantly different from carbon losses in treatment TD20 and TD40 ($p=0.207$; $\alpha=0.05$; Wilcoxon). However, greatest carbon losses were observed in chimato compost TD0 followed by chimato compost TD20 then chimato compost TD40 (Figure 2). Carbon losses in TD0, TD20 and TD40 highly correlated with chimato compost piles' prolonged stay in the high thermophilic stage, implying that prolonged stay in the high thermophilic stage (prolonged heat built-up) was responsible for the observed carbon losses (Carr, 1998; CAW, 2012). The heat increased kinetic energy of the chemical species which probably became more volatile and escaped the compost pile. High temperatures in compost piles are symptomatic to rapid active microbial activities likely to generate large heat (WERL, 2005; WSU, 2010). Thus, the observed carbon losses could be attributed to prolonged exothermic decomposition reaction of carbon atoms that induced the observed high-prolonged temperatures (heat built-up) and that released significant quantities of carbon dioxide (Biala, 2011; Biddlestone and Gray, 1987).

Since prolonged stay in the thermophilic stages suggests prolonged active microbial activities, production of excessive methane and carbon dioxides in compost piles TD0 and TD20 was inevitable. TD0 and TD20 relatively contained large quantities of large quantities of hard to digest carbon containing polymers, such carbon atoms were digested for a longer time thereby releasing enormous heat which raised the temperature of the compost piles. In this process, microbes used and recycled limited quantities of nitrogen used as source of building materials of microbe structure and carbon atoms as source of energy (Biala, 2011; Gill et al., 2012).

Secondly, prolonged stay in high thermophilic phase is symptomatic to prolonged generation of large amounts of heat (WERL, 2005; Mlangeni, 2013) likely to increase kinetic energy of chemical species in the compost piles. The prolonged stay in the thermophilic phase cause chemical species such as carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3) and nitrogen oxides (NO_x) acquire kinetic energy that significantly increases chemical species' random motions in the compost piles. The rapid random motion would either trigger faster rates of reaction with other chemical species in the compost pile or accelerates volatilization from the compost piles. Methane (CH_4) species, which has about 300 times impact on climate change (EPA, 2008; Bernal et al., 1998), could readily react with oxygen under aerobic conditions to produce carbon dioxide, which is of less impact thereby significantly reducing carbon emission of more dangerous greenhouse gas. In addition, methanogenesis would likely occur under conditions of high temperatures as well as low supply of ammonia (Biala, 2011; Gill et al., 2012). Ammonia would be readily available in compost piles with greater quantities of nitrogenous feedstock. Volatilization and escape of chemical species especially carbon dioxide (CO_2) and

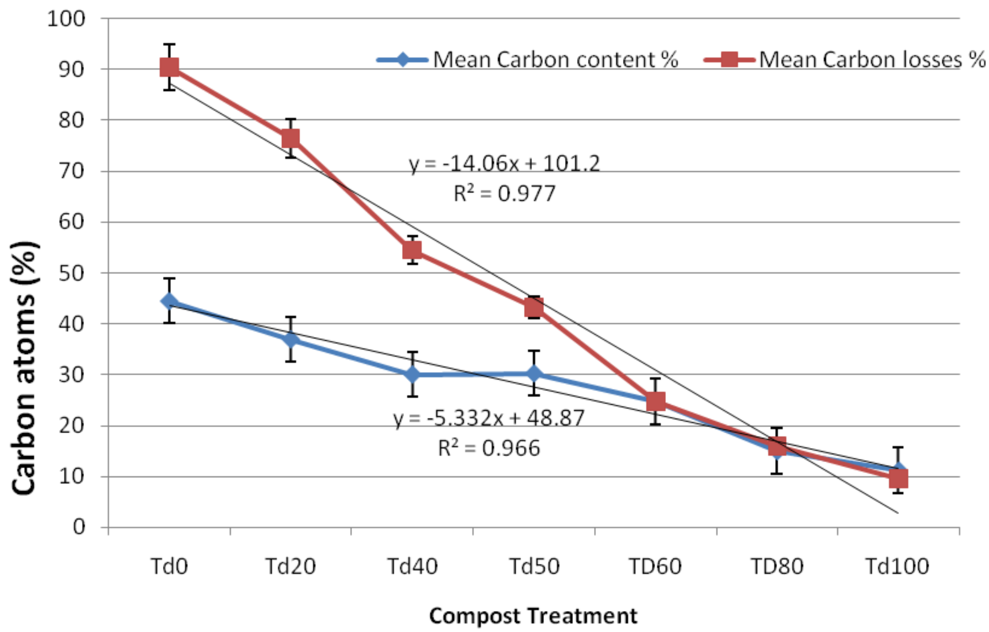

Figure 2. Carbon retainance and losses in various compost treatments.

methane (CH_4) could be enhanced by cracks of compost piles that quickly develops due to high heat built up of compost piles (WERL, 2005; Gill et al., 2012; Biddlestone and Gray, 1987). Thus, carbon dioxide (CO_2) and methane (CH_4) escaped from the piles at fast rate greatly increasing carbon losses of the resultant chimato composts. Therefore, the significant carbon reduction observed in TD0 could be attributable to described carbon losses which would increase carbon emissions. Secondly, microbes had probably plenty nitrogen atoms used to digest available little carbon atoms, which was accomplished with greater speed and significantly short-lived heat build-up of compost piles.

Further analysis has shown that quantity of *T. diversifolia* is negatively correlated with carbon losses in the compost pile up to 60% of *T. diversifolia* content in the compost piles. A linear equation model was developed as follows:

$$Y = -17\text{-}46x + 106.63 \quad (1)$$

Where, y=quantities of *T. diversifolia* and x = carbon lost in the compost piles.

A linear model revealed that *T. diversifolia* is inversely related to carbon losses suggesting that as quantities of *T. diversifolia* increase amounts of carbon lost decreases. Carbon is lost asbeyond 60% of *T. diversifolia* content in the compost piles, carbon losses increased. Carbon could be lost into the surrounding environment as carbonates leachate hence not contributing to carbon emission.

Effect of shorter stay in lower thermophilic stage on carbon emission

As shown in Figure 2, lowest carbon losses were observed in compost TD60 followed by TD50 whose compost piles experienced moderate stay in the high thermophilic stage. The observation implies that compost piles' moderate stay in the high thermophilic phase was due to a balanced blending proportion of carboceous and nitrogenous feedstock. A balanced blending proportion of carboceous and nitrogenous provided an optimum microbial activities that generated an optimum heat build-up in compost piles (Mlangeni and Chiotha, 2013); EPA, 2008; Bernal et al., 1998) that greatly limited production of excessive methane and carbon dioxides. Td50 and Td60 did not experience prolonged heat build-up that forced microbes to reuse the available nitrogen to build up their structures thereby causing significant nitrogen losses nor did they experience short-lived heat build-up which was wet and induced favorable conditions for anaerobic decomposition and significant nitrates losses.

Effect of longer stay in mesophilic stage on carbon emission

As shown in Table 1, TD100 and TD80 experienced a short lived stay in the thermophilic phase and relatively longer stay in the mesophilic phase. The short lived stay in thermophilic phase and longer stay in mesophilic phase resulted from rapid active microbial activities that quickly degraded the ingredients in relatively short time. Thus, less heat was generated in the compost piles

Table 1. Effect of *T. diversifolia* on carbon and nitrogen losses.

Treatment	Initial N (%)	Percentage of N lost (%)	Total C (%)	C lost	Std Error
Td0	1.2	56.67	44.5	90.5	5.0
Td20	1.4	53.57	37.0	76.5	5.0
TD25	1.57	56.05	29.4	67.5	5.0
Td40	1.7	51.76	30.1	44.5	3.5
Td50	2.3	47.83	30.3	33.3	2.0
Td60	2.5	44.80	24.7	24.8	2.5

implying minimal occurrence of decomposition of carboceous materials. The feedstock provided little quantities of hard to digest macromolecules such as cellulose and polyphenols which were easily digested thereby releasing less heat than those with lower composition *T. diversifolia* in the feedstock. Since ammonia volatilization occurs in compost piles with high nitrogen content, Td80 and Td100 were certain to experience reductions of both total Kjeldahl nitrogen and nitrate-N. Nitrates were leached out of the compost piles as leachate or as slurry (Manahan, 2008) collected under the piles. Hence, the short-lived heat build-up in Td80 and Td100 is associated with decreased recorded amounts of total Kjeldahl nitrogen and nitrate-N while the less prolonged were recorded in Td80 and Td100 (Mlangeni, 2013).

Conclusion and recommendations

The results have shown that compost piles that experienced moderate heat build-up experienced minimum carbon losses. Either the heat build-up or the microbial activities or both were responsible for the low carbon losses. However, balanced blending proportion of carboceous and nitrogenous materials in feedstock of compost piles TD50 and TD0 played a significant role in limiting rapid microbial activities which subsequently limited generation of heat in the compost piles. Subsequently, the limited generated heat also limited kinetic energy of chemical species such as NH_4, CO_2 and CH_4 and became more volatile and escaped from the compost piles in large quantities hence the observed greater carbon reduction which increased carbon emission. Making and using chimato composts produced by blending *T. diversifolia* biomass with maize in the ratio of 50:50≤Td/MS≤60:40 greatly reduce compost pile carbon emissions and should be recommended to mitigate effects of climate change.

Conflict of Interests

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

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