OPTIMIZING APPLICATION RATE OF WINERY SOLID WASTE COMPOST FOR IMPROVING THE PERFORMANCE OF MAIZE (*ZEA MAYS* L.) GROWN ON LUVISOL AND CAMBISOL

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Abstract. The use of winery solid waste compost (WSW) on croplands represents an important strategy for WSW management. However, the full benefits of the use of this compost as an organic fertilizer can be derived with accurate recommendations. Hence, a 4×7×2 factorial experiment was conducted under tunnel-house conditions to determine the optimum rates of the WSW compost using quadratic and linear-plus-plateau models. The trial comprised of four WSW compost types applied at various rates (0, 5, 10, 20, and 40 t/ha) on two soils (Luvisol and Cambisol). Generally, stem girth, plant height, leaf number per plant, dry matter yield (DMY), and relative agronomic effectiveness (RAE) increased with higher compost rates. The Principal Component Analysis showed that there is a high correlation between the 20 t/ha rate of WSW compost and DMY. The models had comparable R^2 values. Optimum rates predicted across the two soils by the linear-plus-plateau model ranged from 11.78 to 26.03 t/ha but from 28.16 to 39.53 t/ha with the quadratic model. Higher compost rate predicted by the quadratic model than the linear-plus plateau model resulted in a marginal increase in DMY with few exceptions. Consequently, the linear-plus-plateau model may be a preferred model when predicting the optimum WSW compost rate for maize. The results showed that the WSW compost at a rate of 20 t/ha can be recommended for maize.

Keywords: *dry matter yield, linear-plus-plateau model, maize, organic fertilizer rate, quadratic model*

Introduction

The declining soil fertility and productivity are part of the major problems contributing to food and nutrition insecurities in South Africa and other sub-Saharan African (SSA) countries. Nearly 40% of soils in these countries contain low nutrient capital reserves, less than 10% weatherable minerals, and 25% suffer from aluminium toxicity while 18% have a high leaching potential (Tully et al., 2015). For instance, a reported estimated net annual soil nutrients loss of 7629900 metric tons in SSA and 110900 metric tons in South Africa were reported during 1993-1995 (Henao and Baanante, 1999). Hence, nutrient depletion and organic matter decline in soils in these countries have been attributed to continuous cultivation, inappropriate farming methods, and farmers' poor management practices that include none to low or sub-optimal fertilizer uses (Onduru et al., 2008; Kutu, 2012).

Amelioration of soil nutrients depletion is swiftly achieved with the application of inorganic fertilizers. However, limited access and high costs of inorganic fertilizers are some of the major constraints restricting the reliance on their use by smallholder farmers in SSA (Onduru et al., 2008; Kihara et al., 2016). The integrated use of chemical and organic sources such as manures and composts is widely recognized as a way of sustainably increasing crop productivity (Baghdadi et al., 2018). This strategy improves soil organic matter, soil structure, water-holding capacity, nutrient cycling and cation exchange capacity, and the soil's biological activity (Mahmood et al., 2017). Compost application on soil may also help in disease and pest control (Erhart and Hartl, 2010).

Wine production often results in the generation of huge amounts of by-products mainly consisting of organic wastes, wastewater, greenhouse gas emissions, and inorganic residues (Teixeira et al., 2014). The organic wastes produced during winemaking include grape pomace (seeds, pulp and skins, grape stems, and grape leaves) while the inorganic waste components include diatomaceous earth, bentonite clay, and perlite (Teixeira et al., 2014). The resulting composting products of these wastes have been reported to possess great potential for use as nutrients and organic matter sources (García-Martínez, 2009; Masowa et al., 2018). Several studies have indicated the positive effects of the application of composted winery and distillery waste on various crops (García-Martínez, 2009; Masowa et al., 2016, 2021; Raquel et al., 2018). However, the determination of optimum application rates of WSW compost for judicious use on croplands has not gained much attention in previous studies. The application of adequate amounts of nutrients is a key aspect for improving crop production and optimizing yield (Alonso et al., 2016) since optimal nutrients uptake only takes place when nutrients are adequately provided in balanced quantities to satisfy plants' needs (Sala et al., 2015).

Mathematical models have been used to describe the response of crops to fertilization (Bullock and Bullock, 1994; Mahd, 2008). However, the ability of a model to account for the gap between applied nutrient and plant nutrient demand, and to accurately predict the optimum nutrient required is often affected by factors such as temperature, rainfall (timing, intensity and amount), and several other interconnected variables (Morris et al., 2018) including farmers' management practices. Cerrato and Blackmer (1990) reported that the selection of one model over the others deserves more attention than it has received in the past particularly when making decisions concerning amounts of fertilizer required for profitable crop production. Xia and Yan (2011) reported that the quadratic model as opposed to the exponential and square root models best describes crop yield response to fertilizer rates and gives the optimal fertilizer rates considering environmental and economic effects. Similarly, an earlier study by Bélanger et al. (2000) also revealed that the quadratic model was more appropriate than the exponential and square root model for describing yield and predicting the optimum fertilizer rates in potato. Nevertheless, a report by Marvi (2008) suggests that the quadratic model tends to overestimate crop response if the maximum point on the curve is used as the best fertilization rate. Results of earlier work by Cerratto and Blackmer (1990) suggest that the linear-plateau model tends to overestimate the maize (*Zea mays* L.) yield in the response curve close to the optimum level of N. Several authors have reported that both linear-plus-plateau and quadratic models tend to perform better in cases of yield stagnation (Hafner, 2003; Brisson et al., 2010; Finger, 2010; Michel and Makowski, 2013). Considering the above-mentioned information, this study was initiated to (i) compare the performance of two mathematical models (quadratic and linear-plus-plateau) and (ii) determine the optimum application rate of the WSW compost and their effects on growth and yield of maize.

Materials and methods

Description of the study site

A pot experiment was conducted in 2017 (from November to December) under a tunnel-house for 7 weeks at the North-West University Experimental Farm (25°48’ S, 25°38’ E), Mafikeng, South Africa. The maximum temperature of 28°C in the tunnel-house during the day was maintained using thermostatically activated fans and a wet wall cooling system.

Description of WSW compost production processes and compost analysis

The aerobic-thermophilic production process of WSW compost types and their physico-chemical properties have been presented in an earlier study (Masowa et al., 2018). Briefly, the WSW compost types produced comprised inoculated compost with an initial heap height (hereafter referred to as pile size) of 1 m (INC1), inoculated compost with pile size of 1.5 m (INC1.5), uninoculated compost with pile size of 1 m (UNC1), and uninoculated compost with pile size of 1.5 m (UNC1.5). The compost piles were prepared by mixing the filter materials and waste plant materials at a ratio of 40:60 on a percent volume basis. The effective microorganisms (EM) inoculant was used for microbial inoculation. The pH(KCl) values of the composts ranged from 9.68 to 9.76 while the electrical conductivity varied between 9.03 and 10.23 dS/m. The measured total contents of N, P, K, and Na in composts ranged from 1.23 to 1.80%, 4.87 to 6.04 g/kg, 2.10 to 2.56%, and 5.03 to 6.20 g/kg, respectively.

Experimental design, treatments and procedure

The pot experiment (*Figure 1*) comprised of a 4×7×2 factorial experiment fitted in a completely randomized design with the treatment factors comprising of four WSW compost types, each applied at seven rates (0, 5, 10, 20, 40, 80, and 100 t/ha dry weight) in two different soils. Each treatment combination was replicated four times. Surface soils (0-15 cm) were collected from the cropland of the North-West University Experimental Farm located in Mafikeng (25°48’ S, 25°38’ E) and from the farmer’s field in Ventersdorp (26.2774°S, 26.7614°E) both located in the North-West Province of South Africa. The soil from Mafikeng is classified as Ferric Luvisol while the soil from Ventersdorp soil is classified as Ferralic Cambisol (World Reference Base for Soil Resources, 2015). For the purposes of this paper, the soils from Mafikeng and Ventersdorp will hereafter be referred to as Luvisol and Cambisol, respectively. A surface soil sample was collected for the determination of physical and chemical properties prior to the commencement of the trial. The results showed that Luvisol had 5.1% clay (hydrometer method), 0.42% organic C (Walkley-Black method), pH (H_2O) of 6.77, 6.95 mg/kg total mineral-N (0.5 M K_2SO_4), 80 mg/kg P (Bray-1), 235 mg/kg exchangeable K, 10 mg/kg exchangeable Na, 555 mg/kg Ca and 293 mg/kg Mg (1 N NH_4OAc). A sample of Cambisol test values of 6.3% clay, 1.13% organic C, 6.06 pH (H_2O), 19.35 mg/kg total mineral-N, 75 mg/kg Bray-1 P, 168 mg/kg exchangeable K, exchangeable Na content of 5 mg/kg, and exchangeable Ca and Mg contents of 648 and 228 mg/kg, respectively (Non-Affiliated Soil Analyses Work Committee, 1990).

The air-dried soils were passed through a 6 mm sieve to remove stones and plant roots. Following this, the plastic pots (30 cm diameter) were filled with 12 kg of soil. Each compost type was mixed with the soil based on the calculated weight of soil used per pot and an assumption of the weight of soil (2 million kg) per hectare furrow slice (Masowa et al., 2016). The holes at the bottom of each pot were blocked using cotton wool in order to prevent soil losses. Pots were watered with municipal water, thereafter allowed to equilibrate for 5 hours prior to sowing three seeds of maize (cv. WE6206B) in each pot. Maize seedlings in each pot were thinned down to two seedlings after one week of seedling emergence. The pots received uniform irrigation throughout the period of plant growth. The trial was terminated at 7 weeks after planting by harvesting plant shoots. The seedlings in pots treated with composts at 80 and 100 t/ha died after showing signs of salt stress one week after emergence. Consequently, soil samples were collected from each pot and analyzed for exchangeable soil-Na content. The soil test results revealed that the application of WSW compost at 80 and 100 t/ha significantly increased the exchangeable soil-Na content by up to 175%, which may be the reason for the death of the seedlings (data not shown).

Figure 1. *An experimental layout in completely randomized design for the pot experiment of maize cultivation*

Data collection

The morphological and chlorophyll content data were collected prior to harvesting of shoots. Chlorophyll content was measured around the mid-point of a healthy and longest leaf using a portable CCM-200 *plus* chlorophyll content meter (Opti-Sciences Inc, USA). The morphological data collected include the number of functional leaves per plant, plant height, and stem diameter. The functional leaves per plant were counted manually. Plant height was measured using a measuring tape from the soil surface up to the tip of the highest leaf (Ayub et al., 2012). The stem diameter was measured 10 cm from the soil surface using a Vernier caliper and thereafter converted to girth using the *Equation 1* (Ukonze et al., 2016):

$$\text{Stem girth} = \text{stem diameter} \times \pi\ (pi) \qquad \text{(Eq.1)}$$

Maize shoots harvested from the soil surface using a sharp knife were washed with deionized water, then oven-dried at 70°C to constant weight for dry matter yield (DMY) determination. The computation of the relative agronomic effectiveness (RAE) followed the equation adapted from Law-Ogbomo et al. (2012):

$$\text{RAE}\ (\%) = (\text{DMY}_\text{T} - \text{DMY}_\text{C})/(\text{DMY}_\text{C}) \qquad \text{(Eq.2)}$$

where: DMY_T = maize dry matter yield from compost treated pots, DMY_C = maize dry matter yield from control pots.

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Data analysis

Data on plant growth, chlorophyll content and DMY were subjected to analysis of variance (ANOVA) using the statistical analysis system (SAS) software 9.4. The significant differences among treatment means were detected by the Duncan Multiple Range test at $p<0.05$. The analysis of the correlations between maize growth parameters and dry matter yield was done using the IBM SPSS Statistics software (Version 23). Principal component analysis (PCA) (XLSTAT 2021 statistical software) was aimed at revealing the relation among the examined compost rates and maize growth parameters as well as DMY. The communalities values of the variables were calculated using the IBM SPSS Statistics software (Version 23). Bartlett’s test of sphericity was done at 5% level of significance (Jordaan et al., 2015).

Linear-plus-plateau and quadratic polynomial models were fitted to the DMY data using the NLIN and PROC REG procedures of SAS software 10.0, respectively, to determine the optimum application rate and DMY (Cerrato and Blackmer, 1990; Moswatsi et al., 2013). The quadratic polynomial model is defined by equation 3 below:

$$Y = a + bX + cX^2 \tag{Eq.3}$$

where: Y = dry matter yield (g/pot); X = application rate (t/ha); a (intercept); b (linear coefficient); and c (quadratic coefficient) (Moswatsi et al., 2013).

The linear-plus-plateau is defined by equation 4 below:

$$Y = a + bX \tag{Eq.4}$$

If X is less than C

$$Y = P \tag{Eq.5}$$

if X is greater and equal to C
where: Y = dry matter yield (g/pot); X = application rate (t/ha); a (intercept); b (linear coefficient); b (linear coefficient), C (critical rate of fertilization, which occurs at the intersection of the linear response and the plateau lines), and P (plateau yield) are constants obtained by fitting the model to the data (Cerrato and Blackmer, 1990).

Results

Growth attributes, leaf chlorophyll content, DMY and RAE

The ANOVA showed that variation of WSW composts with microbial inoculation and pile size did not induce significant effects on maize growth attributes, leaf chlorophyll content, DMY and RAE. The measured plant growth attributes and DMY were significantly influenced by the soil type, compost type and application rate while chlorophyll content and RAE were influenced by the compost type and application rate (*Table 1*). Plants grown on Luvisol had a higher mean number of functional leaves per plant but had thicker stems, taller stalks and higher DMY when grown on Cambisol. The different composts significantly improved the number of functional leaves per plant, chlorophyll content, stem girth, plant height and DMY relative to the control. In general, chlorophyll content, mean number of functional leaves per plant, plant height, DMY and RAE increased with increasing compost rates.

Table 1. *Effects of soil type, compost type and compost application rate on maize growth attributes, dry matter yield (DMY) and relative agronomic effectiveness (RAE)*

Treatments	Number of functional leaves per plant	Leaf chlorophyll content (CCI)	Stem girth (mm)	Plant height (cm)	DMY (g/pot)	RAE (%)
Soil type						
Luvisol	11.63^{a}	5.22^{a}	58^{b}	117^{b}	71^{b}	97^{a}
Cambisol	10.00^{b}	5.90^{a}	64^{a}	135^{a}	104^{a}	58^{b}
p-value	<0.001	0.069	<0.001	<0.001	<0.001	<0.001
Compost type						
INC1	10.92^{a}	5.73^{a}	62^{a}	128^{a}	92^{a}	82^{a}
UNC1	10.96^{a}	5.48^{a}	61^{a}	128^{a}	91^{a}	81^{a}
INC1.5	11.04^{a}	5.81^{a}	61^{a}	127^{a}	88^{a}	74^{a}
UNC1.5	10.87^{a}	5.08^{a}	61^{a}	126^{a}	88^{a}	73^{a}
Control	8.68^{b}	3.5^{b}	53^{b}	104^{b}	53^{b}	-
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	0.462
Compost rate (t/ha)						
0	8.68^{e}	3.50^{c}	53^{c}	104^{d}	53^{d}	-
5	9.82^{d}	4.02^{c}	60^{b}	119^{c}	75^{c}	44^{c}
10	10.45^{c}	4.22^{c}	60^{b}	121^{c}	82^{b}	62^{b}
20	11.5^{b}	5.53^{b}	63^{a}	131^{b}	99^{a}	98^{a}
40	12.03^{a}	8.33^{a}	64^{a}	140^{a}	103^{a}	106^{a}
p-value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Means with the same letter(s) within a column and treatment are not significantly different at the 5% probability level

The interaction effect of soil type and application rate significantly influenced the number of functional leaves per plant (*Figure 2A*) and DMY (*Figure 2B*). The highest value of the mean number of functional leaves per plant was recorded from 40 t/ha rate (12.88) under the Cambisol, while the lowest value was obtained from the untreated control (7.75) under the Luvisol. The DMY given by the 20 and 40 t/ha rates in each soil type were statistically at par and higher than that given by the remaining rates.

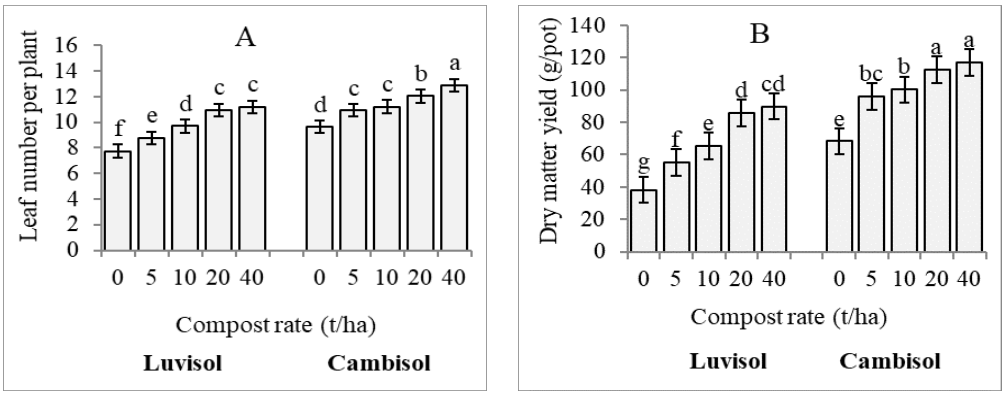

Figure 2. *Interaction effect of soil type and compost rate on the (A) leaf number per plant ($p < 0.001$) and (B) dry matter yield ($p = 0.011$). Means with the same letter(s) are not significantly different. Bars indicate the standard error of the treatment mean*

Significant interaction effect of soil type, compost type and compost rate on the number of functional leaves per plant and RAE was observed (*Table 2*). The mean number of functional leaves per plant ranged from 7.75 (untreated control) to 11.62 (INC1 at 40 t/ha) under the Luvisol, and from 9.62 (untreated control) to 13 (UNC1 and INC1.5 applied at 40 t/ha) under the Cambisol. In most cases, the 20 and 40 t/ha rates gave significantly higher mean number of functional leaves per plant than the 5 and 10 t/ha rates. However, the 20 and 40 t/ha rates were statistically at par in their effects on the number of functional leaves per plant. Except for INC1 at 5 t/ha under the Luvisol, the remaining treatments gave significantly higher values of the mean number of functional leaves per plant in comparison with the control of each soil type. The RAE values ranged from 34% with INC1 (5 t/ha) to 165% with UNC1 (40 t/ha) under the Luvisol, and from 34% with UNC1.5 (5 t/ha) to 80% with INC1.5 (40 t/ha) under the Cambisol. The RAE values obtained from the 20 t/ha rate were significantly higher than those recorded at 5 and 10 t/ha under Luvisol. Similar results were recorded from the 40 t/ha rate except under the INC1 treatment in which the 10 t/ha rate was statistically at par with it under the Luvisol. An increase in the application rate of each compost type from 20 to 40 t/ha within each soil type did not result in a significant difference in the RAE value.

Table 2. *Interaction effect of soil type, compost type and compost rate on the number of functional leaves per plant and relative agronomic effectiveness*

Treatments	Application rate (t/ha)	Number of functional leaves per plant		Relative agronomic effectiveness (%)	
		Luvisol	Cambisol	Luvisol	Cambisol
INC1	5	8.00^{hi}	11.00^{de}	34^{f}	50^{ef}
	10	9.87^{f}	11.00^{de}	81^{de}	53^{ef}
	20	11.12^{de}	12.00^{bc}	142^{abc}	67^{ef}
	40	11.62^{cd}	12.75^{ab}	153^{ab}	74^{def}
UNC1	5	8.62^{gh}	11.00^{de}	51^{ef}	43^{ef}
	10	9.75^{f}	11.37^{cde}	72^{def}	52^{ef}
	20	10.75^{e}	12.00^{bc}	127^{abc}	67^{ef}
	40	11.25^{cde}	13.00^{a}	165^{a}	68^{ef}
INC1.5	5	9.25^{fg}	10.75^{e}	56^{ef}	40^{ef}
	10	9.62^{f}	11.25^{cde}	70^{def}	42^{ef}
	20	11.00^{de}	12.50^{ab}	124^{bc}	67^{ef}
	40	11.00^{de}	13.00^{a}	111^{cd}	80^{ed}
UNC1.5	5	9.12^{fg}	10.87^{de}	46^{ef}	34^{f}
	10	9.50^{f}	11.25^{cde}	78^{de}	46^{ef}
	20	11.00^{de}	11.62^{cd}	119^{bc}	69^{ef}
	40	10.87^{de}	12.75^{ab}	122^{bc}	71^{def}
Control	0	7.75^{i}	9.62^{f}	-	-
p-value		0.032		<0.001	
CV (%)		4.55		32.75	

Means with the same letter(s) for each variable are not significantly different at the 5% probability level; CV = coefficient of variance

PCA and correlations among the growth parameters and DMY

The correlations among the maize growth parameters, chlorophyll content and DMY were highly significant ($p<0.01$; *Table 3*). The results of the PCA show that all the variables that were included in the factor analysis had Kaiser-Meyer-Olkin values ranging from 0.793 to 0.863, and were above the acceptable value of 0.500. The communalities values of the variables ranged from 0.785 to 0.978, and were higher than the acceptable value of 0.300. Bartlett's test of sphericity was also significant ($p<0.0001$). Given these overall indicators, factor analysis was suitable to increase the interpretability of agronomic data and for selecting a suitable compost rate for improving maize dry matter yield. The PC1 accounted for 90.95%, whilst the PC2 accounted for 6.24% of the variation (*Figure 3*). The agronomic parameters were loaded on the PC1. The 20 t/ha rate loaded the number of functional leaves per plant, stem girth and DMY, while the 40 t/ha loaded plant height and leaf chlorophyll content.

Table 3. *Correlation between maize growth parameters, leaf chlorophyll content, and dry matter yield in Luvisol and Cambisol*

Parameters	**Leaf number per plant**	**Leaf chlorophyll content**	**Stem girth**	**Plant height**	**Dry matter yield**
	Luvisol				
Leaf number per plant	1				
Leaf chlorophyll content	0.630**	1			
Stem girth	0.639**	0.467**	1		
Plant height	0.907**	0.742**	0.649**	1	
Dry matter yield	0.937**	0.706**	0.630**	0.942**	1
	Cambisol				
Leaf number per plant	1				
Leaf chlorophyll content	0.899**	1			
Stem girth	0.839**	0.720**	1		
Plant height	0.941**	0.911**	0.865**	1	
Dry matter yield	0.890**	0.746**	0.924**	0.911**	1

**Correlation was significant at the 0.01 level

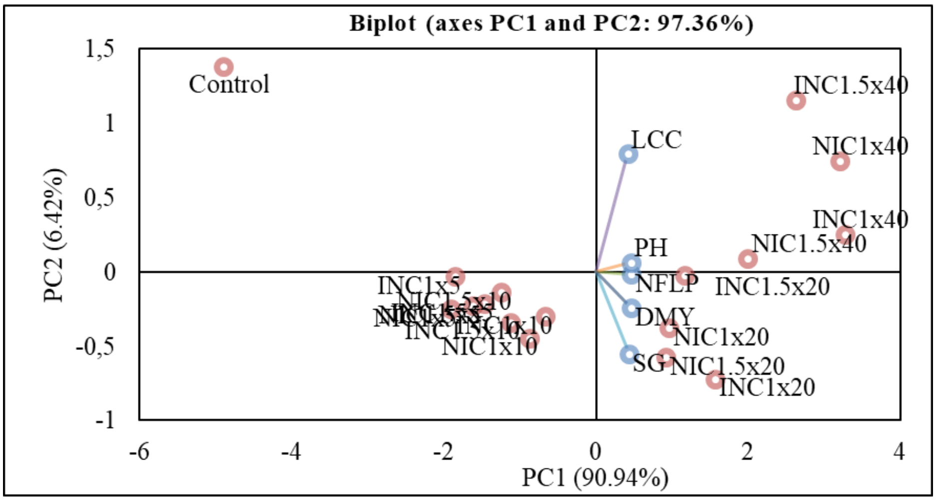

Figure 3. *Principal component biplot showing the variations between the number of functional leaves per plant (NFLP), leaf chlorophyll content (LCC), stem girth (SG), plant height (PH), dry matter yield (DMY) in response to compost type and compost rate across the soil type. (INC1x5, INC1x10, INC1x20 and INC1x40 denote INC1 applied at 5, 10, 20 and 40 t/ha, respectively; UNC1x5, UNC1x10, UNC1x20 and UNC1x40 denote UNC1 applied at 5, 10, 20 and 40 t/ha, respectively)*

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Optimum compost application rate and dry matter yield

The quadratic model predicted higher optimum rates for each compost type as compared to the linear-plus-plateau model but with DMY that was nearly similar to those predicted by the linear-plus-plateau model (*Table 4*). The optimum rates predicted by the linear-plus-plateau model ranged from 11.78 to 26.03 t/ha while the predicted rates by the quadratic model ranged from 28.16 to 39.53 t/ha. In general, greater R^2 values were obtained from the relationship between predicted optimum application rate and dry matter yield under Luvisol compared to the Cambisol. Nevertheless, both models gave significant R^2 values that were either equal or nearly equal for each compost type.

Table 4. *Predicted compost application rates and dry matter yield*

Treatments	Linear-plus-plateau model			Quadratic model		
	Application rate (t/ha)	**Dry matter yield (g/pot)**	R^2	**Application rate (t/ha)**	**Dry matter yield (g/pot)**	R^2
Luvisol						
INC1	21.34	95.41	0.93***	32.96	98.69	0.93***
UNC1	26.03	99.74	0.92***	39.53	99.69	0.92***
INC1.5	16.24	81.96	0.78***	28.35	87.60	0.79***
UNC1.5	20.06	84.53	0.79***	30.78	88.87	0.80***
Cambisol						
INC1	11.78	115.00	0.64**	29.29	122.69	0.62*
UNC1	12.00	112.97	0.76***	28.16	120.81	0.74***
INC1.5	23.18	120.63	0.71***	33.52	121.90	0.74***
UNC1.5	14.23	114.69	0.83***	29.96	121.07	0.83***

***significant at $p<0.0001$; **significant at $p=0.0002$; *significant at $p=0.0003$

Discussion

The positive results on the number of functional leaves per plant, stem girth, plant height, chlorophyll content, and DMY following application of WSW compost soil can be attributed to the soil ameliorative effects of compost. Compost or organic wastes improve the soil structure, water retention, cation exchange capacity, and air content of the soil, microbiological activity (Demir and Gülser, 2015), and increase plant nutrients, particularly N, P (Tambone et al., 2007) and K (Kabil et al., 2015). The ability of WSW compost to release plant-available N and K in the soil had been reported through a laboratory incubation experiment (Kutu and Masowa, 2018). Hence, the general increase in the measured growth parameters following an increase in the compost rate may be attributed to the increased plant availability N from the WSW compost. Masowa et al. (2016) reported a similar finding on the maize growth parameters and DMY. The observation that the various compost types and application rates exerted similar effects on maize growth parameters and DMY across both soil types suggests that EM inoculation and pile size may not necessarily exert influence on the agronomic potential of WSW compost. This may be attributed to the non-significant effects exerted by EM inoculation and pile size on the quality parameters of WSW compost as reported by Masowa et al. (2018).

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It is evident that the higher available N in the Cambisol resulted in higher stem girth, plant height, and DMY than in the Luvisol across the compost types and application rates. However, the higher available N in Cambisol did not translate to a higher number of functional leaves per plant and chlorophyll content in the Luvisol. The general and significant increase in the measured growth parameters, chlorophyll content, and DMY given by 20 and 40 t/ha rates as compared to the 5 and 10 t/ha rates may be attributed to the increase in the availability of soil nutrients under these rates. Adejumo et al. (2010) also reported the highest maize plant height, DMY, leaf area, and grain yield at a higher dose (40 t/ha) of municipal solid waste compost. The recorded significant and positive correlation of DMY with the measured growth parameters affirms the DMY as one of the key indicators of plant growth (Laekemariam and Gidago, 2013). Carpici and Celik (2010) reported a positive and significant correlation between maize dry forage yield and plant height. Kumar and Singh (2004) similarly reported a significant and positive correlation of maize dry forage yield per plant with plant height, number of leaves per plant, and stem diameter.

Except for the UNC1 in Luvisol, quantitatively higher optimum compost rates predicted in both soils by the quadratic model were only associated with marginal yield increases compared to yield predicted by the linear-plus-plateau model. The use of the quadratic model has been reported to lead to overestimation of fertilizer recommendations derived from crop responses to fertilizer (Bullock and Bullock, 1994; Hochmuth et al., 2011) particularly when the maximum point on the curve is taken as the best fertilization rate (Mahd, 2008). However, both models gave R^2 values that were either equal or nearly equal for both composts. Hence, the use of R^2 statistics to select the best model for predicting the optimum rate and DMY may constitute a limitation in this study. This finding also confirms that fitting the same dataset in both models can give comparable R^2 values, but different optimal application rates of fertilizer, which is in agreement with an earlier report by Xia and Yan (2011). This further affirms the non-reliability of the R^2 value as an absolute indicator for predicting the optimum fertilizer rate since it varies with the chosen model (Bachmaier and Gandorfer, 2012). The more than 90% for the R^2 values in the Luvisol suggests that the models described the data quite well under INC1 and UNC1 treatments. The recorded high R^2 values in Luvisol than Cambisol indicate that the predicted rates and DMY may be highly influenced by the soil type. Nevertheless, the use of the predicted optimum DMY may be an option for selecting the best model. Therefore, the linear-plus-plateau model is preferable to the quadratic model for predicting optimum WSW compost rate for maize dry matter production. The range of 11.78 to 39.53 t/ha for the predicted optimum rates in both soils was within the range of those used in practice which ranges from 10 to 40 t/ha (fresh weight) (Elherradi et al., 2005). The current predicted optimum rates of the WSW compost types contradict the earlier optimum rate of 87 t/ha predicted by Masowa et al. (2016) for maize grown in sandy soil under greenhouse conditions suggesting that the optimum rates for these composts are not only site-specific but also dependent on soil types and characteristics. Alivelu et al. (2006) recommended the site-specific or season-specific knowledge of crop nutrient requirements and nutrient supply from the soil in order to achieve maximum yields. The 20 t/ha rate gave the DMY and RAE values that were comparable to those obtained from the 40 t/ha rate and it is within the range of the optimum rates predicted by the linear-plus-plateau model. Consequently, the 20 t/ha rate may be a better WSW compost rate when growing maize for dry matter yield. The PCA also indicated that there is a high correlation between the 20 t/ha rate of WSW compost and DMY.

Conclusion

The application of compost improved growth and DMY of maize. The measured growth parameters and DMY increased with increasing compost rates. The differences in WSW compost associated with pile size and EM inoculation do not influence the compost agronomic effectiveness because the compost types exerted similar effects on the measured growth parameters. The quadratic model predicted quantitatively higher optimum rates associated with marginally higher DMYs compared with the DMYs predicted by the linear-plus-plateau model. Thus, the linear-plus-plateau model is preferable to the quadratic model for predicting optimum rates of WSW compost for maize dry matter production. The 20 t/ha compost application rate is recommended for optimum DMY of maize. However, follow-up field experiments across several sites with different climate and soils are highly recommended to validate the predicted rates.

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