Emirates Journal of Food and Agriculture. 2021. 33(7): 565-574
doi: 10.9755/ejfa.2021.v33.i7.2721
http://www.ejfa.me/

RESEARCH ARTICLE

Effects of complementary and sole applications of inorganic fertilizers and winery solid waste compost on maize yield and soil health indices

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ABSTRACT

The development of plant nutrition systems that enhance soil productivity through the use of mineral fertilizers combined with organic fertilizers has recently gained increased attention. Two field experiments were conducted in 2018 (from February to June) and 2018/19 (from December 2018 to April 2019) to assess the effects of complementary application of inorganic nitrogen (N) and phosphorus (P) fertilizers (INPF) and winery solid waste (WSW) composts on maize yield and soil health indicators. The INPF and optimum rates of microbially inoculated and uninoculated WSW compost types were combined at different ratios (0:0, 75:25, 50:50, 25:75 and 0:100 w/w) to supply proportionate N and P amount. The recommended INPF rates for maize (200 kg N ha^{-1} and 90 kg P ha^{-1}) were mixed and included as a standard control. The interaction of compost type and application rate had no significant effects on total biomass yield (TBY), grain yield (GY) and harvest index (HI). The compost type had significant effects on GY and HI in 2018/19. The TBYs obtained from the 50:50, 75:25 and 100:0 compost-INPF combinations were significantly higher than that recorded from untreated control across the compost types in 2018. The 25:75 and 50:50 compost-INPF combinations gave GYs which were significantly higher than that obtained from the untreated control in 2018/19. In many instances, soil pH and the contents of organic C, NO_3, P, K, Na and Zn recorded from treatments with the different mix ratios of compost and INPF were higher than that recorded from the untreated control. Grain yield correlated significantly and positively with the contents of soil NH_4 (r = 0.59) and P (r = 0.53) indicating that these nutrients contributed to the final GY. In conclusion, the joint application of compost and INPF at 25:75 and 50:50 ratios appears promising for improving GY. Increase in soil K content suggested the need for a controlled application of WSW compost followed by frequent soil testing exercise to monitor and avoid unnecessary K build-up that may induce the deficiencies of other plant nutrients.

Key words: effective microorganisms inoculant, grain yield, soil health indicators, winery solid waste compost; *Zea mays*

INTRODUCTION

Soil quality or health is defined as the capacity of the soil to function within the ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Bonilla et al., 2012). Soil health indicators are a composite set of measurable soil properties, which relate to functional soil processes and can be used to evaluate the health status of soil, as affected by soil use, management and climate change drivers (Allen et al., 2011; Cardoso et al., 2013). Soil properties with a rapid response to the natural or anthropogenic actions are considered as good indicators of soil health (Cardoso et al., 2013). Soil biological and biochemical properties, particularly those involved in energy flow and nutrient cycling have been found to respond to even minimal changes in soil conditions and management (Baba et al., 2015). The physical indicators of soil health include soil texture, aggregation, moisture, porosity, and bulk density, while chemical indicators comprise total C and N, mineral nutrients, organic matter, cation exchange capacity, to mention a few (Cardoso et al., 2013). An optimal level of soil organic matter content is essential to all soil properties and processes (Lal, 2011). The soil

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Received: 21 March 2021; **Accepted:** 18 June 2021

organic matter and total N are the major determinants and indicators of soil quality and fertility and are closely related to soil productivity in an agricultural ecosystem (Adeboye et al., 2011). The biological indicators include measurements of microorganisms and macroorganisms, as well as their activities (for example, enzyme activity) or functions (Martinez-Salgado et al., 2010). The soil microbial biomass is a small but key component of the active soil organic matter pool and serves as a source and sink of soil nutrients (Adeboye et al., 2011).

The pertinence of minimizing crop fertilization costs has prompted the adoption of innovative and cost-effective soil enhancing mechanisms such as organic soil amendments (Baloyi et al., 2014), which enhance soil fertility by improving soil physico-chemical properties (Anwar et al., 2017). Recently, increased attention is given to the development of plant nutrition systems that maintain or enhance soil productivity through a balanced use of mineral fertilizers combined with organic sources of plant nutrients (Vasileva and Kostov, 2015). There is still a dearth of research regarding the extent at which organic fertilizers could increase the efficiency of applied mineral fertilizers in sustaining soil and crop productivity (Adamu and Leye, 2012; Baloyi et al., 2014). Baghdadi et al. (2018) reported that treatment with chicken manure (50%) combined with NPK fertilizer (50%) resulted in dry matter yields of forage silage corn and soybean that were the same as that resulting from 100% NPK fertilizer. Furthermore, the combination of NPK fertilizer (50%) and chicken manure (50%) resulted in increased height, growth rates and leaf area index of silage corn and soybean compared with chicken manure applications alone (100%). Makinde and Ayoola (2010) also showed that maize yields from sole organic fertilizer application (10 t ha^{-1}) are significantly lower than yields from either sole inorganic fertilizer (70 kg N and 13 kg P_2O_5 ha^{-1}) or a combined application of organic and inorganic fertilizers (5 t organic fertilizer, 35 kg N and 6.5 kg P_2O_5 ha^{-1}). Nitrogen, P and K uptakes by tomato plants were observed to be significantly higher in both organically and inorganically fertilized plants than their un-fertilized counterparts (Babajide and Salami, 2012). Geng et al. (2019) concluded based on their research findings that the appropriate organic substitution is crucial to yield, excessive organic fertilizer substitution leads to insufficient N and accumulation of P and K, potentially endangering the environment. Earlier studies indicated that the application of WSW compost could be a useful source of K and Zn for maize (Masowa et al., 2016; Kutu and Masowa, 2018). However, the N and P contents in maize shoots from the compost treatments were lower than the critical level of N and P. This suggests supplementary N and P needs through the use of higher concentrations of soluble N and P fertilizers when this compost is used. Given the interconnectedness of soil health challenges, sustainable agriculture and food security, the pertinence of maintaining qualitative soil health cannot be overemphasised. This study was conducted to determine the effects of sole and combined application of WSW compost and inorganic NP fertilizers on maize yield and soil health attributes.

MATERIALS AND METHODS

Description of study site

Two field experiments were conducted in 2018 (Experiment 1) and 2018/19 (Experiment 2) at the Exeprimental Farm of North-West University (25°48’ S, 25°38’ E), Mafikeng, South Africa. Experiment 1 began in February 2018 and ended in June 2018 while Experiment 2 commenced in December 2018 and ended in April 2019. Mafikeng has a typical semi-arid tropical Savannah climate with summer mean annual rainfall of 571 mm (Materechera and Medupe, 2006). Table 1 shows the rainfall and temperature data recorded during the first experiment (2018) and second exeperiment (2018/19). Temperatures were higher in the Experiment 2 than in the Experiment 1. Selected physico-chemical properties of the soil were determined before planting following standard laboratory procedures described by NASAWC (1990) (Table 2). Materechera and Medupe (2006) classified this soil as Ferric Luvisol using an international classification under the FAO/UNESCO system.

Experimental design and procedures

The full details of the production process and the chemical properties of the WSW compost produced with and without addition of effective microorganisms inoculant have been previously presented by Masowa et al. (2018). The inoculated (INC1) and uninoculated (UNC1) WSW compost types were initially evaluated through a 7 weeks tunnel house maize pot trial at 0, 5, 10, 20 and 40 kg ha^{-1} application rates to predict their optimum rate based on maize dry matter yield using a quadratic polynomial model as described by Moswatsi et al. (2013). The predicted optimum rates of INC1 and UNC1 were 32.96 and 39.53 t ha^{-1}, respectively. The total N contents of INC1 and UNC1 as reported earlier by Masowa et al. (2018) were 2.56% and 2.10%, respectively. The INPF and obtained optimum rate of each compost type were combined at different ratios (0:0, 75:25, 50:50, 25:75 and 0:100, w/w) to supply proportionate N and P amount in the field trial. Inorganic K fertilizer was excluded from the fertilizer programme due to the high amount of available K in WSW compost. The optimum inorganic NP fertilizer rate (200 kg N ha^{-1} and 90 kg P ha^{-1}) was included as a standard control (Soropa

Table 1: Monthly rainfall and temperature data for the Experimental Farm of North-West University for the duration of experimental periods (SAWS 2018, 2019)

Experiment 1	Climate data	February	March	April	May	June
(2018)	Rainfall (mm)	108.8	90	27.6	26.0	0
	Maximum temperature (°C)	29.7	29.6	27	25.2	23.5
	Minimum temperature (°C)	17.4	15.4	12.5	7.0	3.9
Experiment 2	**Climate data**	**December**	**January**	**February**	**March**	**April**
(2018/19)	Rainfall (mm)	90.6	30.2	133.4	36.2	122.8
	Maximum temperature (°C)	34.8	34.5	31.5	33.7	26.6
	Minimum temperature (°C)	19.6	18.9	17.5	17.1	13.7

Table 2: Physico-chemical properties of soil from the Exeprimental Farm of North-West University

Soil property	Values
Clay (%)	5.1
Sand (%)	69.4
Silt (%)	25.5
Textural class	Sandy loam
pH (H_2O) 1:2.5	6.77
NO_3-N (mg kg^{-1})	4.00
NH_4-N (mg kg^{-1})	2.95
Total mineral N (mg kg^{-1})	6.95
Bray-1 P (mg kg^{-1})	80
K (mg kg^{-1})	235
Ca (mg kg^{-1})	555
Mg (mg kg^{-1})	293
Na (mg kg^{-1})	10

et al., 2012). All treatments in the trials were laid out as split-plot arrangement fitted in a randomized complete block design with three replicates. The compost type was the main plot while the compost rate was the sub-plot. Each sub-plot measured 4 m x 3.6 m. The plots were 1 m apart, while the blocks were 1.5 m apart.

The WSW compost was spread uniformly on each plot as per treatment and worked lightly into the soil using hand hoe at one week before seed sowing to ensure thorough mixing with the soil. Broadcasting of the inorganic NP fertilizers was done at planting but with N split-applied with 50% at planting, and the remaining amount applied at the V10 stage to promote nutrients accumulation (Ransom, 2013). The sources of N and P were limestone ammonium nitrate (28% N) and single superphosphate (10.5% P), respectively. Intra-row distance between the plants was 25 cm while inter-row distance was 70 cm, resulting in six maize rows per plot. The inter-row spacing of maize seeds generally ranges from 70 to 100 cm, while the intra row spacing varies between 20 and 30 cm (Desta, 2015). Two maize (cv. WE6206B) seeds were sown per hole followed by thinning to one plant per stand at one week after emergence. Weeding and irrigation were kept uniform for all treatments throughout the period of plant growth.

Data collection

Grain and total biomass yield

At harvest, cobs were removed from plants from the central four rows of each plot and the grains were shelled. The grain moisture content was determined using a Near Infrared Reflectance Grain Analyzer. After adjusting the grain moisture content to 12%, grain yield (GY) was converted into kg ha^{-1} using the formula below:

$$GY\ (kg\ ha^{-1}) = \{GY\ (kg)/\text{Area harvested } (4\ m \times 2.1\ m)\} \times 10\,000\ m^2\ ha^{-1}\}\ldots\ldots \quad \text{(Equation 1)}$$

For the determination of total biomass yield (BY), four randomly selected plants with cobs from the central rows were cut from the soil surface using a sharp knife, washed with deionized water, oven-dried (70°C) and then weighed. The BY thus obtained from each plot was converted into kg ha^{-1} using the equation below:

$$BY\ (kg\ ha^{-1}) = \{\text{Dry weight of 1 plant (kg)} \times (\text{plant population } ha^{-1})\}\ldots\ldots\ldots \quad \text{(Equation 2)}$$

Estimation of the harvest index (HI) for each treatment was undertaken using the following formula cited by Iqbal et al. (2015):

$$HI = (\text{grain yield}/\text{biomass yield}) \times 100\ldots \quad \text{(Equation 3)}$$

Soil physico-chemical properties

The assessment of bulk density and porosity took place at maize tasselling stage and at harvest. The bulk density was determined by collecting a known volume of soil using a metal ring pressed into the soil (0 - 15 cm depth), and determining the weight after drying (McKenzie et al., 2004; Lal and Shukla, 2004). The porosity of the soil was estimated using the following equation and assuming that the soil particle density is 2.65 g cm^{-3} (Brady, 1984):

$$\text{Porosity} = \{1 - (\rho_b/\rho_s) \times 100\}\ldots\ldots \quad \text{(Equation 4)}$$

whereby: ρ_b and ρ_s represent soil bulk density and particle density, respectively.

Soil samples (0-15 cm depth) were collected from each plot, bulked according to their treatments at crop harvest. Subsequently, the soil chemical health indicators that included pH (KCl), organic C (Walkley-Black method), available P (Bray-1), extractable K, Na, Zn

(NASAWC, 1990) and mineral N (Okalebo et al., 2002) were analyzed.

Data analysis

Measured data on maize total BY, grain yield and soil physical properties were subjected to analysis of variance and separation of differences between treatment means involved Fisher's protected least significant difference (LSD) test at 5% level of significance using a SAS software version 9.4. The collected data on soil chemical properties were subjected to classical statistical methods to obtain the minimum, maximum, mean, median, skewness (Phefadu and Kutu, 2016). Simple Pearson's correlation analysis was run for soil properties, BY, GY and HI at crop harvest using the IBM SPSS Statistics software (Version 23).

RESULTS

Treatments and their interaction effects on total biomass yield, grain yield and harvest index

The effect of compost type and application rate on total BY, GY and HI at crop harvest is depicted in Table 3. The compost type significantly affected GY and HI in 2018/19. The GY and HI in 2018/19 recorded from INC1 and UNC1 were statistically at par with those obtained from the INPF treatment. With reference to the untreated control, compost and INPF application significantly increased the GY and HI in 2018/19. The application rate significantly affected total BY in 2018, GY in 2018/19 and HI in both experiments. The total BY obtained from treatments with 50:50, 75:25 and 100:0 compost-INPF combinations were 19693, 18835 and 20618 kg ha^{-1} respectively, and were significantly higher than 16161 kg ha^{-1} for the untreated control in 2018. However, the total BY obtained from the various compost-INPF combinations was statistically comparable to that recorded from the sole INPF treatment in 2018. Grain yields obtained from the 25:75 and 50:50 compost-INPF combinations were 6649 and 6246 kg ha^{-1} respectively and were significantly higher than 4557 kg ha^{-1} for the untreated control in 2018/19. The 25:75 and 50:50 compost-INPF combinations gave quantitatively higher GY than the 75:25 and 100:0 compost-INPF combinations in both experiments. The HI value recorded from the 25:75 compost-INPF combination was significantly higher (58%) than those recorded from the 50:50, 75:25 and 100:0 compost-INPF combinations (49%, 45% and 41%, respectively) in 2018. In 2018/19, the various compost-INPF combinations except 100:0 compost-INPF combination resulted in significantly higher HI values than the untreated control. The HI values recorded from the compost-INPF combinations were statistically at par with that recorded from sole INPF treatment in 2018/19.

Treatments and their interaction effects on soil bulk density and porosity at tasselling stage and crop harvest

Table 4 indicates the effect of compost type and application rate on soil bulk density and porosity at tasselling stage and crop harvest. The compost type significantly affected soil bulk density and porosity at tasselling stage in both experiments. It also significantly influenced these parameters at crop harvest only in 2018/19. The soil bulk densities measured at tasselling stage from the INC1 and UNC1 were significantly lower than that from the untreated control in 2018. In 2018/19, significant decreases in bulk density were recorded from INC1 and UNC1 treatments with reference to both the untreated control and INPF at tasselling stage. Both INC1 and UNC1 treatments resulted in significantly lower bulk densities than the untreated control and INPF at crop harvest in 2018/19. Soil porosity was increased significantly following compost application with reference to the untreated control at tasselling stage in both experiments. Soil porosity values recorded from the INC1 and UNC1 treatments were quantitatively higher than that recorded from the INPF treatment and the untreated control at crop harvest in 2018. The UNC1 application resulted in higher and significant increase in soil porosity followed by the INC1 application at crop harvest in 2018/19. The soil bulk density was significantly influenced by the application rate in both experiments, while porosity was not affected by the application rate only at crop harvest in 2018.

The various compost-INPF combinations resulted in significantly lower soil bulk densities than the untreated control at tasselling stage in 2018. In 2018/19, lower soil bulk densities were recorded only from 50:50, 75:25 and 100:0 compost-INPF combinations with reference to the untreated control at tasselling stage. Only 75:25 and 100:0 gave lower soil bulk densities in comparison with both the untreated control and INPF at crop harvest in 2018. The compost-INPF combinations resulted in significantly lower soil bulk densities and higher soil porosity than the INPF, but only soil bulk density and porosity recorded from the 50:50 compost-INPF combination were statistically comparable to that recorded from the untreated control at crop harvest in 2018/19. Only 100:0 of compost-INPF combination gave significantly higher soil porosity than both the untreated control and INPF at crop harvest in 2018/19. Compared to the untreated control, the various compost-INPF combinations induced significant increases insoil porosity at tasseling stage in 2018. In 2018/19, the various application rates except 25:75 compost-INPF combinations resulted in significant increase in soil porosity with reference to the untreated control at tasselling stage. The 75:25 and 100:0 compost-INPF combinations resulted in significantly

Table 3: Effect of compost type and application rate on total biomass, grain yield and harvest index in Experiment 1 (2018) and Experiment 2 (2018/19)

Treatments	Total biomass (kg ha^{-1})		Grain yield (kg ha^{-1})		Harvest index (%)	
	2018	2018/19	2018	2018/19	2018	2018/19
Compost type						
INC1	19329	15382	9381	5979a	49	39a
UNC1	19154	15871	9154	6106a	48	39a
INPF	19400	16843	10503	6654a	54	40a
Control	16161	14311	8499	4557b	52	32b
LSD$_{(0.05)}$	2923	2630	2408	885	11	3.31
p-value	0.170	0.285	0.566	<0.001	0.6139	<0.001
CV (%)	11	20	19	18	17	11
Application rate (WSWC:INPF)						
0:0	16161c	14311	8499	4557b	52ab	32c
25:75	17820bc	16125	10365	6649a	58a	42a
50:50	19693ab	16157	9552	6246a	49bc	39ab
75:25	18835ab	14248	8594	5641ab	45bc	40ab
100:0	20618a	15975	8560	5633ab	41c	36bc
INPF	19400ab	16843	10503	6654a	54ab	40ab
LSD$_{(0.05)}$	2584	3895	2047	1221	9.16	4.85
p-value	0.023	0.673	0.160	0.012	0.01	0.003
CV (%)	12	21	19	18	15	11
Compost type x application rate interaction						
F-test probability	ns	ns	ns	ns	ns	ns

Means with the same letter(s) within the same column and treatment factor are not significantly different at 5% probability level; where letters are not presented indicate no significant differences; INC1 = inoculated winery solid waste compost; UNC1 = uninoculated winery solid waste compost; WSWC = winery solid waste compost; INPF = nitrogen and phosphorus fertilizers; LSD = least significant difference; CV = coefficient of variation

Table 4: Effect of compost type and application rate on soil bulk density and porosity at tasselling stage and crop harvest in Experiment 1 (2018) and Experiment 2 (2018/19)

Treatments	Tasselling stage				Crop harvest			
	Bulk density (g cm^{-3})		Porosity (%)		Bulk density (g cm^{-3})		Porosity (%)	
	2018	2018/19	2018	2018/19	2018	2018/19	2018	2018/19
Compost type								
INC1	1.17b	1.14c	56a	57a	1.16a	1.22b	56a	54b
UNC1	1.14b	1.15c	57a	57a	1.13a	1.13c	58a	57a
INPF	1.23ab	1.21b	54ab	54b	1.24a	1.43a	54a	46c
Control	1.30a	1.27a	51b	52c	1.23a	1.36a	54a	49c
LSD$_{(0.05)}$	0.11	0.0525	4.02	1.98	0.10	0.0735	4	2.775
p-value	0.030	<0.001	0.028	<0.001	0.094	<0.001	0.139	<0.001
CV (%)	6.94	5.35	5.32	4.37	6.65	6.95	5.25	6.54
Application rate (WSWC:INPF)								
0:0	1.30a	1.27a	51.0d	52.1d	1.23a	1.36ab	54.0a	48.8de
25:75	1.19bc	1.21b	55.3bc	54.3cd	1.16ab	1.21cd	56.2a	54.5bc
50:50	1.21bc	1.20b	54.7bc	54.8c	1.17ab	1.29bc	56.0a	51.2cd
75:25	1.13cd	1.12c	57.3ab	57.8b	1.14b	1.12de	56.8a	57.6ab
100:0	1.09d	1.05d	58.8a	60.3a	1.11b	1.09e	58.2a	58.8a
INPF	1.23ab	1.21b	54.0c	54.4c	1.24a	1.43a	53.7a	46.2e
LSD$_{(0.05)}$	0.0829	0.0591	2.966	2.23	0.0843	0.0981	3.2474	3.7027
p-value	<0.001	<0.001	<0.001	<0.001	0.032	<0.001	0.069	<0.001
CV (%)	5.89	4.25	4.54	3.39	6.08	6.64	4.92	5.92

Means with the same letter(s) within the same column and treatment are not significantly different at 5% probability level; INPF = nitrogen and phosphorus fertilizers; INC1 = inoculated winery solid waste compost; UNC1 = uninoculated winery solid waste compost; LSD = least significant difference; CV = coefficient of variation; WSWC = winery solid waste compost

higher soil porosity than the INPF at tasselling stage in both experiments.

The interaction effect of compost type and application rate on soil bulk density and porosity measured at tasselling stage and crop harvest was significant only in 2018/19 (Table 5). At tasselling stage, soil bulk density ranged from 1.06 g cm^{-3} with UNC1-INPF (100:0) to 1.30 g cm^{-3} with the untreated control in 2018 and from 1.02 g cm^{-3} INC1-INPF (100:0) to 1.27 g cm^{-3} with the untreated control in

Table 5: Interaction effect of compost type and application rate on soil bulk density and porosity at tasselling stage and crop harvest in Experiment 1 (2018) and Experiment 2 (2018/19)

Treatments	Tasselling stage				Crop harvest			
	Bulk density (g cm^{-3})		Porosity (%)		Bulk density (g cm^{-3})		Porosity (%)	
	2018	2018/19	2018	2018/19	2018	2018/19	2018	2018/19
INC1+INPF (25:75)	1.19	1.23a	55	53.6e	1.18	1.30bc	55	51cd
INC1+INPF (50:50)	1.23	1.18abcd	54	55.6bcde	1.18	1.35abc	55	49.1cde
INC1+INPF (75:25)	1.14	1.12bcd	57	57.6bcd	1.19	1.11e	55	58.1a
INC1+INPF (100:0)	1.12	1.02e	58	61.5a	1.10	1.13de	59	57.2ab
UNC1+INPF (25:75)	1.18	1.19abc	56	54.9cde	1.14	1.12e	57	57.9a
UNC1+INPF (50:50)	1.18	1.22ab	55	54.0de	1.15	1.24cd	57	53.4bc
UNC1+INPF (75:25)	1.12	1.11cde	58	58.0abc	1.09	1.14de	59	57.1ab
UNC1+INPF (100:0)	1.06	1.08de	60	59.1ab	1.12	1.05e	58	60.4a
INPF	1.23	1.21abc	54	54.4cde	1.24	1.43a	54	46.2e
Control	1.30	1.27a	51	52.1e	1.23	1.36ab	54	48.8de
$\text{LSD}_{(0.05)}$	0.14	0.0964	5	3.638	0.13	0.12	5	4.5283
p-value	0.081	0.001	0.082	0.001	0.333	<0.001	0.394	<0.001
CV (%)	6.94	4.23	5.32	3.78	6.65	5.73	5.25	4.90

Means with the same letter(s) within the same column are not significantly different at 5% probability level; where letters are not presented indicate no significant differences; INC1 denotes inoculated winery solid waste compost; UNC1 denotes uninoculated winery solid waste compost; INPF = nitrogen and phosphorus fertilizers; LSD = Least significant difference; CV = coefficient of variation

2018/19. Treatments with INC1-INPF (75:25; 100:0) and UNC1-INPF (75:25; 100:0) significantly decreased soil bulk density with reference to the untreated control at tasselling stage in 2018/19. Both INC1-INPF (100:0) and UNC1-INPF (100:0) gave significantly lower soil bulk densities than the INPF in 2018/19 at tasselling stage. At crop harvest, the soil bulk density varied between 1.09 g cm^{-3} with UNC1-INPF (75:25) and 1.24 g cm^{-3} with the INPF in 2018 and between 1.05 g cm^{-3} UNC1-INPF (100:0) and 1.43 g cm^{-3} with INPF in 2018/19. The compost-INPF combinations except the INC1-INPF (50:50) combination decreased soil bulk density significantly with reference to the INPF at crop harvest in 2018/19. Only treatments with INC1-INPF (25:75; 50:50) had insignificantly lower soil bulk densities than the untreated control at crop harvest in 2018/19. The soil porosity ranged from 51% with the untreated control to 60% with UNC1-INPF (100:0) in 2018 and from 52.1% with the untreated control to 61.5% with INC1-INPF (100:0) in 2018/19 at tasselling stage. The INC1-INPF (75:25; 100:0) and UNC1-INPF (75:25; 100:0) combinations significantly increased the soil porosity with reference to the untreated control at tasselling stage in 2018/19. The INC1-INPF (100:0) and UNC1-INPF (100:0) gave significantly higher values of soil porosity than the INPF at tasselling stage in 2018/19. The soil porosity varied between 54% with the untreated control/INPF and 59% with INC1-INPF (100:0)/UNC1-INPF (75:25) in 2018 and between 46.2% with the untreated control and 60% with UNC1-INPF (100:0) in 2018/19 at crop harvest. There was no significant difference in soil porosity among the compost-combinations in 2018. The compost-INPF combinations except INC1-INPF (50:50) combination significantly increase the soil porosity at crop harvest in 2018/19 with reference to the INPF. The soil porosity recorded from the treatments with INC1-INPF (25:75; 50:50) was statistically comparable to that recorded from the untreated control at crop harvest in 2018/19.

Soil chemical properties measured at crop harvest

Table 6 presents soil chemical properties measured at crop harvest in 2018 and 2018/19. The soil pH ranged from 6.29 with the sole INPF to 7.58 with the INC-INPF (100:0) in 2018, and from 6.35 with the sole INPF to 7.90 with INC1-INPF (100:0) in 2018/19. The compost-INPF application increased soil pH with reference to both the untreated control and sole INPF treatment in 2018. Only treatments with the INC1-INPF (25:75; 50:50) combinations did not increase the soil pH compared to the untreated control in 2018/19. The soil organic C ranged from 0.58% with the untreated control to 1.15% with the UNC1-INPF (100:0) in 2018 and from 0.48% with INPF to 1.17% with the INC1-INPF (100:0) in 2018/19. Compared to control and sole INPF treatment, the UNC1-INPF (50:50) gave lower soil organic C in 2018, but higher soil organic C in 2018/19, whereas the remaining treatments resulted in higher soil organic C in both experiments. The 100:0 compost-INPF gave higher values of soil organic C than the remaining treatment combinations. The compost-INPF combinations increased the soil P, K, Na and Zn contents as compared to the untreated control in both experiments. Treatments with INC1-INPF (25:75) and UNC1-INPF (50:50) gave lower soil P content when compared to sole INPF in 2018, whereas all treatment combinations except UNC1-INPF (50:50) resulted in lower soil P content than the sole INPF treatment in 2018/19. The highest NO$_3$ content of 40.50 mg kg^{-1} was recorded from the UNC1-INPF (100:0) in 2018. In 2018/19, the compost-INPF combinations

Table 6: Soil chemical properties measured at crop harvest in Experiment 1 (2018) and Experiment 2 (2018/19)

Treatments	2018								2018/19							
	$pH_{(KCl)}$	SOC (%)	NO_3	NH_4	P	K	Na	Zn	$pH_{(KCl)}$	SOC (%)	NO_3	NH_4	P	K	Na	Zn
			(mg kg^{-1})								(mg kg^{-1})					
INC1+INPF (25:75)	7.07	1.04	14.60	4.25	129	295	85	10.13	7.14	0.58	9.35	1.70	118	248	43	15.40
INC1+INPF (50:50)	7.09	0.60	4.63	2.20	166	806	58	9.40	7.19	0.71	19.00	2.55	104	550	80	11.00
INC1+INPF (75:25)	7.26	1.03	14.08	4.05	177	841	75	5.99	7.53	0.72	5.33	1.45	80	480	90	8.72
INC1+INPF (100:0)	7.58	1.13	10.22	2.65	142	1257	85	8.42	7.90	1.17	11.96	1.55	62	590	103	12.60
UNC1+INPF (25:75)	7.12	0.45	29.14	2.95	188	837	45	7.58	7.18	0.74	7.44	1.35	131	400	70	11.68
UNC1+INPF (50:50)	7.22	0.37	3.03	1.60	109	759	55	11.03	7.38	0.76	10.71	1.70	184	343	63	23.80
UNC1+INPF (75:25)	7.22	0.55	4.34	2.15	177	1476	63	7.90	7.53	0.92	13.57	1.70	82	500	78	10.16
UNC1+INPF (100:0)	7.49	1.15	40.50	4.30	151	1526	88	5.93	7.78	0.91	21.38	1.70	81	1080	148	7.60
INPF	6.29	1.07	21.74	3.20	142	221	83	10.45	6.35	0.48	6.93	1.15	152	200	45	14.60
Control	6.98	0.58	4.51	3.00	38	205	50	5.07	7.32	0.50	4.07	1.95	30	193	40	4.44
Minimum	6.29	0.37	3.03	1.60	38	205	45	5.07	6.35	0.48	4.07	1.15	30	193	40	4.44
Maximum	7.58	1.15	40.50	4.30	188	1526	88	11.03	7.90	1.17	21.38	2.55	184	1080	148	23.80
Mean	7.13	0.80	14.68	3.04	142	822	69	8.19	7.33	0.75	10.97	1.68	102	458	76	12.00
Median	7.17	0.82	12.15	2.98	147	821	69	8.16	7.35	0.73	10.03	1.70	93	440	74	11.34
Standard deviation	0.35	0.31	12.44	0.93	43.84	487	16.31	2.07	0.43	0.21	5.69	0.38	45.26	261	33	5.27
SEM	0.11	0.10	3.93	0.29	13.86	154	5.16	0.66	0.14	0.07	1.80	0.12	14.31	83	10.37	1.67
Skewness	-1.50	-0.11	1.14	0.10	-1.58	0.13	-0.15	-0.15	-1.17	0.66	0.78	1.22	0.33	1.54	1.11	1.08
CV (%)	4.90	39.08	84.75	30.73	31	59	24	25.31	5.84	28.07	51.86	22.54	44	57	43	43.89

SOC = soil organic carbon; INC1 = inoculated winery solid waste compost; UNC1 = uninoculated winery solid waste compost; INPF = nitrogen and phosphorus fertilizers; SEM = standard error of mean; CV = coefficient of variation

gave higher amounts of NO_3 than the untreated control and the sole INPF.

Only treatments with UNC1-INPF (100:0) and INC1-INPF (25:75; 75:25) gave higher NH_4 contents than the untreated control and INPF in 2018. In 2018/19, only INC1-INPF (50:50) resulted in higher NH_4 content than the untreated control, but all treatment combinations gave higher NH_4 contents than the sole INPF treatment. The soil chemical parameters gave the mean and median values that were close or equivalent to each other. Among the soil chemical properties, only NO_3, NH_4 and K were positively skewed in 2018. Negative and very high coefficients of skewness were given by soil pH in both experiments and P content in 2018. The soil pH, organic C, NH_4, P, K, Na and Zn were normally distributed with coefficients of skewness below 0.5 in 2018, whereas only soil pH and P followed the normal distribution in 2018/19.

Correlations of soil properties against total biomass yield, grain yield and harvest index

The results of correlation analysis of soil properties with total BY, GY and HI are indicated in Table 7. The soil NH_4 content showed positive and highly significant correlations with GY and HI. The soil P content gave positive and significant correlation with GY, but it showed positive and highly significant correlation with total BY. The total BY correlated significantly and positively with the soil K content.

DISCUSSION

Increased biomass production depends on the agricultural practices and genetic modifications that would increase plant growth and produce augmented dry matter (Lima et al., 2017). The increase in total BY observed from treatments with 50:50, 75:25 and 100:0 compost-INPF combinations compared to the untreated control across the compost types may be attributed to improved crop growth due to enhanced nutrients availability and other soil properties in 2018. However, treatments with compost-INPF combinations presented a total biomass that was statistically comparable to that obtained from the sole INPF treatment in 2018. The increase in GY and HI given by WSW compost types and INPF in comparison to the untreated control across the application rate during the drier 2018/19 season may be due to the increased availability of nutrients for crop uptake. Muhammad and Jan (2016) attributed the increase in HI following compost application to greater yields, yield components and grain N use efficiency due increased nutrient availability for uptake. The enhanced GY with 25:75 and 50:50 combinations of compost and INPF across the compost types in 2018/19 may be due to increased N and P availability in the soil for crop uptake. Shah et al. (2007) also reported higher grain yield from a treatment that received compost and N from urea in 25:75 and 50:50 ratios. The finding that the total BY was positively correlated with the grain yield is consistent with the findings reported by Iptaş and Yavuz (2008) and Tajul et al. (2013). Additionally, Inamullah et al. (2011)

Table 7: Coefficient of correlation(r) analysis of soil properties against total biomass yield, grain yield and harvest index

Parameters	BD	Porosity	pH	NO_3	NH_4	P	K	Na	Zn	OC
TBY	-0.26	0.27	-0.17	0.05	0.35	0.59**	0.48*	-0.09	0.09	0.19
GY	-0.23	0.26	-0.27	0.14	0.59**	0.53*	0.21	-0.19	-0.10	0.07
HI	-0.12	0.15	-0.28	0.17	0.59**	0.35	-0.05	-0.23	-0.18	-0.05

BD = soil bulk density; OC = soil organic carbon; TBY = total biomass yield; GY = grain yield; HI = harvest index; *Correlation is significant at the 0.05 level; **Correlation is significant at the 0.01 level

reported that HI showed positive and highly significant correlation with the grain yield.

The various combinations of compost and INPF induced significant increases in soil porosity in 2018/19 compared to the untreated control. The increased soil porosity following compost application indicates the soil's permeability not only for water, but also for air and roots (Cardoso et al., 2013). This affirms that the addition of organic materials represents a viable solution to the reduction of soil compaction by decreasing the soil bulk density (Hamza and Anderson, 2005). Research conducted by Mbagwu (1992) showed that the decrease in bulk density recorded from the soil treated with rice-shaving and poultry manure were directly related to increased organic matter which played a significant role in reducing the compaction of soil. The soil pH showed a trend of increasing with compost application rate. This indicated that an increase in WSW compost rate leads to a greater supply of exchangeable cations such as Ca, K, Na and Mg in the soil due to the alkaline nature of these WSW compost types as indicated by their higher pH reported earlier by Masowa et al. (2018). Therefore, the use of WSW compost on acidic soil may be beneficial to increase the soil pH to the optimum level for maximum plant nutrient availability. Although the increases in soil organic C following sole application of WSW compost or combined application of WSW compost and INPF were observed with reference to the untreated control, the soil organic C in the root zone was found to be below the threshold level of 1.5 to 2.0% (Lal, 2016).

The compost-INPF combinations increased the soil P, K, Na and Zn contents as compared to the untreated control in both experiments. The increases in the contents of P, K, Na and Zn in the soil indicated that the WSW compost may serve as P, K and Zn source. However, the increases in soil K and Na contents from the WSW compost-INPF (100:0) may result in K (Xu et al., 2020) and Na (Wakeel, 2013) reducing the uptake of the other plant nutrients. The soil K content from treatments with either sole compost or combination of compost and INPF were found to be in the high to excessive range (Horneck et al., 2011). Consequently, a frequent application of WSW compost on soil is not recommended to avoid unnecessary K build-up in the soil. Treatments with INC1-INPF (25:75) and UNC1-INPF (50:50) gave lower soil P content as compared to sole INPF in 2018, whereas all treatment combinations except UNC1-INPF (50:50) resulted in lower soil P content than the sole INPF treatment in 2018/19. The soil P contents from treatments with sole or combined application of compost and INPF were found to be in the high to excessive range (London, 2013; Horneck et al., 2011). It is vital to note that the significant correlation between maize grain yield and the contents of soil NH_4 and P indicates that these soil health properties contributed to the final grain yield. Consequently, the contents of soil NH_4 and P following the application of compost-INPF play a significant role in the selection of the combination of compost and INPF for higher grain yield.

CONCLUSIONS AND RECOMMENDATIONS

The results of the study revealed that the combined application of winery solid waste compost and INPF holds immense possiblities for the improvement of maize productivity and maintainance of soil health. However, a frequent application of winery solid waste compost on croplands is not recommended to avoid unnecessary build-up of high concentration of soil K that may induce the deficiencies of other plant nutrients. The winery solid waste compost may be used on acidic soils to increase the soil pH to an optimum level for maximum plant nutrient availability and better microbial activity. Maize grain yield correlated positively and significantly with the soil NH_4 and P contents, indicating that these soil health properties contributed to the final grain yield. Therefore, the selection of the combination of compost and INPF for higher grain yields demands the consideration of the contents of soil NH_4 and P following the application of that selected combination.

Authors' contributions

M. M. M. was a doctoral student responsible for the planning of the experiment including data collection and analysis, and preparation and revision of draft manuscript. F. R. K. was the main supervisor of M.M.M involved in the planning of the experiment including funding acquisition, editing and revision of drafts of the manuscript while both A. R. M. and O. O. B were co-supervisors of M.M.M. and contributed equally to the planning, implementation and preparation of the manuscript. Finally, P.D. played a role of funding acquisition and writing of the final manuscript including the various revisions.

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