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Potential of co-application of microbial enriched winery solid waste compost and inorganic fertilizers to enhance maize growth and yield parameters

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Abstract

The present study was conducted to assess the effects of co-application of winery solid waste compost (WWC) and synthetic nitrogen (N) and phosphorus (P) fertilizers (SF) on maize growth and yield parameters. The field experiment was conducted during the 2017/18 and 2018/19 summer cropping seasons. The WWCs (microbially inoculated and uninoculated) and SF were combined at ratios: 0:0, 25:75, 50:50, 75:25, and 100:0 (wt/wt) to attain the amount of N and P supplied by the predicted rates of compost. The optimum SF rate (90 kg/ha P and 200 kg/ha N) for maize was used as a positive control. The non-significant ($p \leq 0.05$) effect of compost type on growth and yield parameters indicated that the microbial inoculation during compost production has no effect on compost quality. Compared with control, WWC-SF combination (50:50) improved grain weight per cob by 18.6% in 2017/18. The increase in the measured yield parameters was quantitatively higher in treatment with the 50:50 WWC-SF mix ratio than in other treatments. Significant and positive correlations exist between growth and yield parameters. In conclusion, the study findings suggest that the combined application of WWC and SF has great potential to enhance the maize growth and yield attributes.

Article highlights

- The influence of co-application of winery solid waste compost (WWC) and inorganic nitrogen and phosphorus fertilizers on maize growth and yield parameters was comparable to that of sole application of either the WWC or the inorganic fertilizers.
- The addition of the effective microorganisms (EM) during composting of winery solid waste had no influence on the agronomic potential of the WWC.
- Positive correlations exist between maize growth and yield parameters as affected by the co-application of the WWC and inorganic fertilizers.

Keywords Agro-industrial waste · Effective microorganisms · Growth attributes · Maize yield indices · Winery solid waste compost

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1 Introduction

The world population is envisaged to go beyond 9 billion people by 2050, and approximately 70% of extra food production is needed to meet the global food demands [1]. The population in the urban areas is also expected to rise with human diets increasingly shifting from staples to processed food fortified with dairy and meat products, thus leading to a higher demand for crop farming that is intensive [2]. Proper food production strategies are required to deal with the predicted rise in global foods demand. Even though many problems (for example, climate change, scarcity of resources and decline in soil quality) were identified to hinder crop farming, a combination of improved crop and agronomical practices was proposed by Fan et al. [3] to deal with the anticipated increase in food demands.

In sub-Saharan Africa, maize (*Zea mays* L.) accounts for 40% of the cereal production with approximately 80% of the production used as food [4]. Its consumption as a stable food differ according to the preferences of food, and economic and social backgrounds [5] while its popularity has steadily increased since the early part of the twentieth century in South Africa and many parts of sub-Saharan Africa [6]. In South Africa for instance, the subsistence and commercial farmers produce maize with the North West Province representing the major white maize producing area accounting for about 20% of all the commercial maize grown [7]. However, huge yield gaps still observed in farmers' fields [8] because of the prevalence of the rapidly declining fertility of soil, and partially due to the continued crop farming with inadequate or no supply of fertilizers to the soils that are naturally infertile [9]. The situation is exacerbated by extreme climate variables such as heat and drought. Yields of maize have assumed an overall increasing trend between 1961 and 2019 in Africa with 126% yield change reported in Southern Africa [10]. However, projections of average crop yields decrease of 18% and 22% in Southern Africa and across sub-Saharan Africa, respectively by 2050 have been reported [11]. Specifically, in South Africa, a maize yield decreases of up to 12% by 2050 due to drier conditions has been predicted [12]. Maize requires substantial quantity of water [13] as well as essential nutrients as compared with other crops [14]. Sosibo et al. [15] urged that farmers to refine the soil fertility management practices because of the unavoidable increases in demand and removal of nutrients as farmers target higher yields.

Maize needs phosphorus (P) and nitrogen (N) for better vegetative growth and grain development [16]. In sub-Saharan Africa, the low soil P and N contents are amongst the major limitations for crop production [17–19]. Low use of chemical N-fertilizer and significant N losses exacerbate the depletion of N in sub-Saharan Africa [19]. Application of chemical fertilizers on soil is regarded the most efficacious way to fix the soil P and N deficiencies; however, the use of chemical fertilizers is restricted by the high cost at the farmers' level [18, 20]. According to Chianu et al. [21], the chemical fertilizers improve crop productivity sustainably by 50 to 100%. Ahmed et al. [22] and Khan et al. [23] reported that the integrated use of chemical and organic fertilizers represents a promising fertilization strategy not only for ensuring a higher crop productivity but also for improved crop production stability.

The increased limitations on the use of landfills and global environmental-related pressures are currently forcing industries to use sustainable waste management technologies [24]. Composting waste has the benefits of reducing the volume of waste in landfills and significantly improves the characteristics of soil and the productivity of land [25]. The use of agro-industrial waste materials as soil amendments has been given a lot of attention in recent times for agronomic applications. Several research trials have shown the desirable results of the application of distillery and winery waste compost on several crops [26–29]. The findings from a preliminary study showed that the maize shoot P and N contents from the treatments with WWC were below the critical level of P and N [26]. This indicated that there is a need for investigations on ways to supplement P and N with SF when applying WWC on maize. Hence, this study aimed to assess the response of maize to different mix ratios of WWC and SF under field conditions. The objectives of the research study were to quantify the effects of (i) co-application and sole application of WWC and SF and (ii) WWC type on maize growth and yield parameters. As far as we know, there is no study that has been conducted to determine the effects of the co-application of WWC and SF on growth and yield parameters of maize under field conditions.

2 Materials and methods

2.1 Study area and compost used in this study

A study was initiated during the summer planting seasons of 2017/18 (February to April) and 2018/19 (December to February) at the North-West University Agricultural Research Farm (25°48′ S, 25°38′ E) located in North West Province of South Africa. According to Materechera and Medupe [30], this area exhibits the characteristics of semi-arid tropical savanna climate and receives an average of 571 mm rainfall per year in summer. The dominant soil form at the experimental site is Ferric Luvisol [30] with a sandy loam texture [27]. The soil at the experimental site had a clay content of 5.1%, organic carbon content of 0.42% (Potassium dichromate method), and a pH_{water} value of 6.77. The soil total mineral N (0.5 M K_2SO_4), P (Bray-1) and exchangeable K contents were 6.95, 80 and 235 mg/kg, respectively [31].

The full details on the production and characterization of WWCs used in this study were presented by Masowa et al. [32]. The WWCs were made in piles with (inoculated—INC1) and without (uninoculated—UNC1) the application of effective microorganisms (EM) inoculant. The commercial EM-1 inoculum used during the compost production had a pH value of 3.34 before activation and contained 6.8 × 107 CFU/mL of lactic acid bacteria (*Lactobacillus casei*) and 2.4 × 102 CFU/mL of yeast (*Saccharomycess cerevisiae*). The total N contents of INC1 and UNC1 were 2.56% and 2.10%, respectively. The INC1 and UNC1 had total P contents of 6.04 and 4.87 g/kg, respectively. The quadratic model was used to predict the optimum application rate of WWC types for optimum maize dry matter production. The predicted rate of INC1 was found to be 33 t/ha whereas that of UNC1 was 40 t/ha (compost on a dry weight basis)].

2.2 Experimental set-up and crop management practices

The treatments for the field experiment comprised of the predicted rate of each WWC type and SF mixed at different ratios: 0:0—control, 25:75, 50:50, 75:25, and 100:0, wt/wt) to attain the amount of N and P supplied by the predicted rates of INC1 (33 t/ha) and UNC1 (40 t/ha). The optimum SF rate (90 kg/ha P and 200 kg/ha N) was also added as a positive control [33]. The experiment was laid out as a split-plot arrangement fitted into a randomized complete block design with three replications. Compost type and application rate were the main plot and subplot, respectively. The sub-plot was 4.0 m long and 3.6 m wide, respectively. A distance between plots and blocks was 1.0 and 1.5 m, respectively. White dent maize (cv. WE6206B) was manually planted (using a hoe at a depth of ~ 10 cm) using the intra-row and inter-row spacing of 0.25 m and 0.70 m, respectively, giving six rows in each plot. Planting was done a week after applying the WWC (dry weight basis). A plant population density of 70,834 plants/ha was used in this study. The cultivar used in this study matures in 80 to 100 days after planting. Phosphorus and N were supplied using single superphosphate (SSP, 10.5%) and limestone ammonium nitrate (LAN, 28%), respectively. The SSP fertilizer and half of the LAN fertilizer were broadcasted at planting, and the remaining LAN fertilizer was broadcasted at the cob development stage. All the plots received the same quantity of irrigation water. The field was kept weed-free by manually removing the weeds using hand hoe throughout the cropping season.

2.3 Collection of agronomic data

Four tagged plants that were randomly selected in the middle four rows in each plot were used for collection of data on growth indices physiological maturity stages. A steel meter tape was used to measure the height of maize plant from the surface of the soil to the tip of the flag leaf. Leaf area index was calculated by dividing the leaf area per plant by the ground area per plant [34]. The length of the cob leaf was measured from the base of the leaf at the stem to the leaf tip using a steel meter ruler, whereas the width of the cob leaf was measured at the mid-portion of the leaf with the highest width. Subsequently, the cob leaf area was calculated using Eq. 1 given by Makinde and Ayoola [35].

$$\text{Leaf area} = [(\text{Length of the leaf}[\text{MM1}] \times \text{Width of the leaf}) \times 0.75][\text{MM1}]\text{Corrected the spelling error} \quad (1)$$

The diameter of the plant stem was measured at 10 cm from the ground using a Vernier caliper. Subsequently, the stem girth was computed using Eq. 2 given by Ukonze et al. [36].

$$\text{Stem girth} = (\text{Stem diameter} \times \pi) \quad (2)$$

At harvest maturity, yield parameters were determined using dehusked cobs harvested from the four-tagged and sun-dried plants mentioned earlier. The length of the cob was measured using a plastic tape measure. Cobs from each plot were weighed to determined cob weight before shelling. After shelling of the cobs manually, grains from each cob were counted and weighed. The weight of 1000 seeds (1000-SW) was determined by weighing a sub-sample of 1000 seeds and then it was adjusted at 12% moisture content. The grain moisture content was determined using the Near-Infrared Reflectance Grain Analyzer.

2.4 Statistical analysis

Data on maize growth and yield parameters were subjected to analysis of variance (ANOVA) and the means were separated by the Fisher's least significant difference (LSD) test at a 5% level of significance using a Statistical Analysis Software 9.4. A generalized linear model was used to determine the compost type, rate, and their interaction effect on growth and yield parameters of maize for each planting season. The correlation analysis was conducted to establish the associations amongst the growth and yield parameters using the SPSS statistical software (IBM SPSS software 23).

3 Results and discussion

3.1 Plant growth parameters at physiological maturity stages

Leaf area index is an essential parameter of plant growth since the effectiveness of photosynthesis relies on the large and deficient assimilating areas, adequate supply of solar and carbon dioxide, and conducive environmental conditions [37]. The interactive effect of compost type and application rate on LAI in 2018/19 was significant (Fig. 1). The observed low mean LAI values ranging from 0.31 with the 25:75 of UNC1-SF to 0.39 with 100:0 of INC1-SF in 2018/19 could relate to planting of an early maturing maize cultivar with lower leaf area per plant [38, 39].

The sole compost and 50:50 WSW compost-INPF combination across the compost type gave significantly higher plant height values than the untreated control in 2018/19 (Table 1). The interactive effect of compost type and rate on plant height in 2018/19 was significant (Fig. 2). The finding that the combinations of WWC and SF gave plant heights that were comparable to that recorded from the sole SF in 2018/19 (Fig. 2) indicates that improved crop growth is attainable with the co-application of WWC and SF, thus decreasing the cost of crop fertilization with sole SF. The increase in plant height also showed an increased availability of nutrients for uptake by plants following SF and WWC applications. This agrees with the earlier study reported by Oad et al. [40] following the co-application of urea and manure. Complementary use of soil organic amendments and zinc fertilizer has also increased plant height of maize [41]. Increased plant height following the co-application of WWC and SF may also lead to an increase in grain yield and biomass. Previous studies have revealed that plant height correlates highly with biomass and grain yield [42–46].

The interactive effect of compost type and rate on stem girth in 2017/18 was significant (Fig. 3). The application of WWC alone gave a significantly highest value of stem girth in 2017/18, albeit statistically comparable with the stem girth values recorded from the WWC-SF treatments. This indicates the beneficial effect of the application of WWC solely or in combination with SF for the plant growth enhancement. A similar study by Afe et al. [47] also revealed an increase in stem girth of maize plants caused by the co-application of inorganic NPK and organic fertilizers. The increase in stem girth shows increased availability of nutrients for plant growth after amending the soil with a both of inorganic and organic fertilizers [48]. It is worth noting that the 100:0 compost-INPF combination across the compost types gave a significantly higher value of stem girth than the sole INPF treatment in 2017/18 (Table 1).

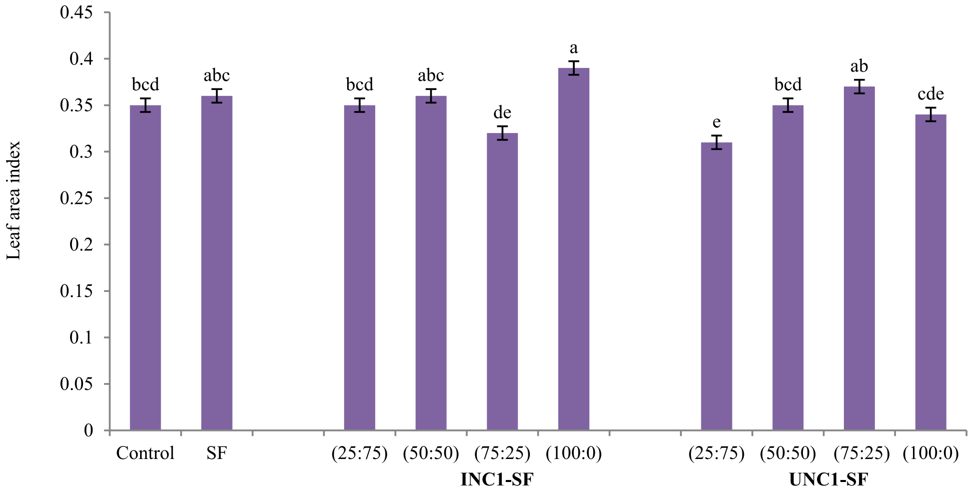

Fig. 1 Interactive effect of compost type and application rate on leaf area index in 2018/19 ($LSD_{(0.05)} = 0.03$). The bars represent the standard error of mean. SF denotes synthetic nitrogen and phosphorus fertilizers; INC1 and UNC1 denote inoculated and uninoculated compost, respectively

Table 1 Response of plant growth parameters to compost type and application rate at crop physiological maturity in 2017/18 and 2018/19

Treatments	Plant height (m)		Stem girth (mm)	
	2017/18	2018/19	2017/18	2018/19
Compost type				
INC1	3.02 a	2.70 a	88.90 a	72.10 b
UNC1	3.03 a	2.68 a	89.80 a	73.10 ab
SF	3.07 a	2.75 a	87.20 a	75.90 a
Control	2.95 a	2.57 b	80.10 b	68.60 c
$LSD_{(0.05)}$ value	0.19	0.08	6.30	2.82
p-value	0.757	0.001	0.032	< 0.001
Coefficient of variation (%)	5.00	5.00	5.00	6.78
Application rate (WWC:SF)				
0:0	2.95 a	2.57 b	80.10 d	68.60 c
25:75	3.08 a	2.67 ab	84.50 cd	70.90 bc
50:50	3.06 a	2.74 a	88.50 bc	72.0 abc
75:25	2.95 a	2.65 ab	90.00 ab	73.50 ab
100:0	3.01 a	2.73 a	94.30 a	74.10 ab
SF	3.07 a	2.75 a	87.20 bc	75.90 a
$LSD_{(0.05)}$ value	0.15	0.12	0.49	4.25
p-value	0.303	0.033	< 0.001	0.019
Coefficient of variation (%)	4.00	5.00	5.00	7.18
Compost type × application rate	ns	*	*	ns

Means followed by the same letter(s) in the same column and treatment factor are not significantly different ($p \leq 0.05$). *INC1* inoculated compost, *UNC1* uninoculated compost, *SF* synthetic nitrogen and phosphorus fertilizers, *WWC* winery solid waste compost, *LSD* least significant difference, *ns* not significant ($p \leq 0.05$); *significant at $p \leq 0.05$

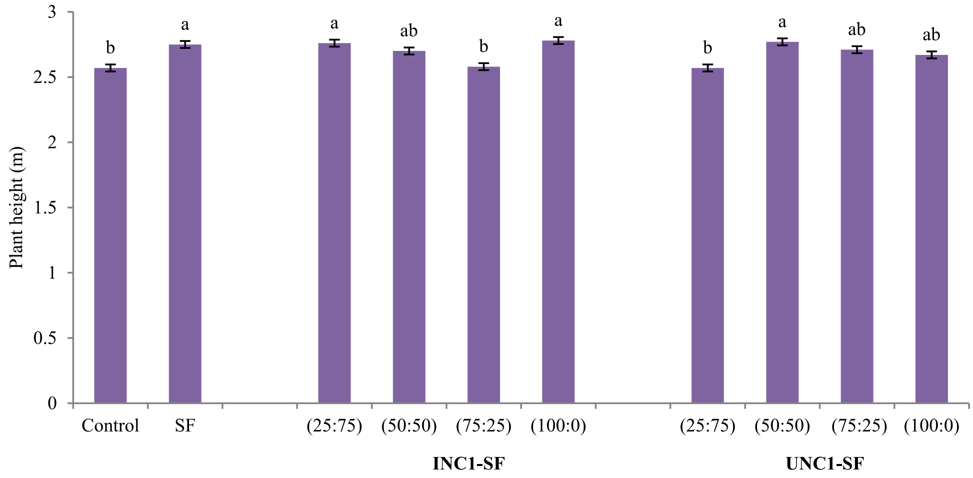

Fig. 2 Interactive effect of compost type and application rate on plant height in 2018/19 ($LSD_{(0.05)} = 0.16$). The bars represent the standard error of mean. SF denotes synthetic nitrogen and phosphorus fertilizers; INC1 and UNC1 denote inoculated and uninoculated compost, respectively

3.2 Yield parameters

Cob length substantially contributes to grain yield of maize by affecting both numbers of seeds per cob and size of seeds [49]. Treated plots had cobs that were significantly longer as compared to cobs from the control plot in 2018/19 (Table 2). This increase in cob length is ascribable to increased availability of nutrients to plants through the improved organic matter decomposition and mineralization processes [50]. In many instances, the increase in the

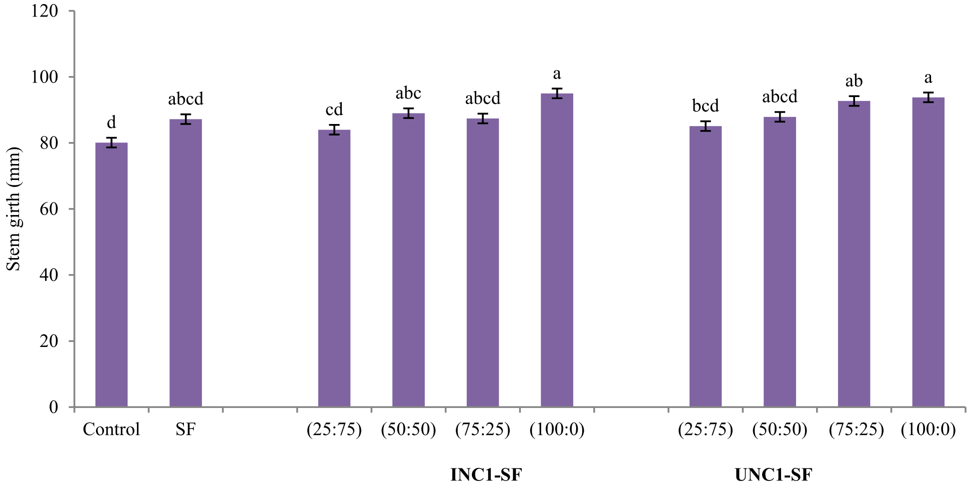

Fig. 3 Interactive effect of compost type and application rate on the stem girth in 2017/18 ($LSD_{(0.05)} = 8$). The bars represent the standard error of mean. SF denotes synthetic nitrogen and phosphorus fertilizers; INC1 and UNC1 denote inoculated and uninoculated compost, respectively

yield parameters was quantitatively higher in treatment with a 50:50 WWC-SF mix ratio than in other treatments. This may be ascribed to the increase in nutrient availability and improved soil conditions following the addition of WWC and SF at 50:50 ratio. Non-significant interactive effect of compost type and rate on the yield indices was observed.

Table 2 Response of yield parameters to compost type and application rate at crop harvest in 2017/18 and 2018/19

Treatments	Cob length (mm)		Cob weight (g)		Grain weight per cob (g)		Grain number per cob		1000-SW (g)	
	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19
Compost type										
INC1	224 a	215 a	158 a	106 a	140 a	74 a	547 a	518 a	256 a	141 a
UNC1	220 a	218 a	149 a	113 a	134 a	77 a	539 a	538 a	248 a	143 a
SF	220 a	204 a	147 a	108 a	132 a	76 a	553 a	472 a	239 a	144 a
Control	222 a	183 b	136 a	92 a	118 a	59 a	523 a	474 a	225 a	126 a
$LSD_{(0.05)}$ value	16	14	26	24	22	18	49	76	34	20
p-value	0.870	< 0.001	0.347	0.353	0.256	0.161	0.707	0.226	0.279	0.225
Coefficient of variation (%)	5.24	8.34	13.00	28.00	12.00	30.00	6.63	18.32	10.00	17.00
Application rate (WWC:SF)										
0:0	222 a	183 b	136 a	92 a	118 c	59 a	523 a	474 a	225 a	126 a
25:75	217 a	214 a	139 a	113 a	126 bc	80 a	539 a	550 a	233 a	146 a
50:50	223 a	219 a	157 a	116 a	140 ab	81 a	549 a	524 a	255 a	150 a
75:25	220 a	214 a	150 a	97 a	134 abc	65 a	523 a	502 a	254 a	129 a
100:0	228 a	219 a	167 a	112 a	149 a	78 a	562 a	535 a	265 a	142 a
SF	220 a	204 ab	147 a	108 a	132 abc	76 a	553 a	472 a	239 a	144 a
$LSD_{(0.05)}$ value	13	21	22	35	19	25	40	110	29	28
p-value	0.590	0.012	0.086	0.674	0.043	0.415	0.256	0.617	0.067	0.408
Coefficient of variation (%)	4.75	8.42	13	28	12	29.13	6.18	18.31	9.85	16.95
Compost × application rate	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Means followed by the same letter(s) in the same column and treatment factor are not significantly different ($p \leq 0.05$). *1000-SW* 1000 seed weight, *INC1* inoculated compost, *UNC1* uninoculated compost, *SF* synthetic nitrogen and phosphorus fertilizers, *WWC* winery solid waste compost, *LSD* least significant difference, *ns* not significant

Table 3 Pearson's correlation matrix of maize growth and yield parameters

Parameters	Plant height	Stem girth	Leaf area index	Cob length	Cob weight	Grain weight per cob	Grain number per cob	1000-SW
Plant height	1							
Stem girth	0.88**	1						
Leaf area index	0.94**	0.90**	1					
Cob length	0.59**	0.57**	0.48*	1				
Cob weight	0.87**	0.89**	0.83**	0.74**	1			
Grain weight per cob	0.92**	0.94**	0.91**	0.67**	0.98**	1		
Grain number per cob	0.55*	0.49*	0.42 ns	0.75**	0.71**	0.63**	1	
1000-SW	0.91**	0.94**	0.94**	0.62**	0.95**	0.99**	0.54*	1

*Significant ($p \leq 0.05$); **highly significant ($p \leq 0.01$); ns, not significant ($p \leq 0.05$); 1000-SW, 1000 seeds weight

3.3 Correlations between maize growth and yield parameters

Significant and positive correlations amongst the growth and yield parameters (Table 3) as affected by the joint application of WWC and SF demonstrate the true relationship between these parameters [51]. Thus, any SF and WWC mix ratio that improves the growth attributes will likely improve yield parameters and ultimately increase the biological and seed yields. Asfaw [52] observed positive and significant correlations between potato tuber yield and growth parameters as affected by the integrated soil amendment practices. Moreover, the author concluded that any management practices that provide favorable influences on the measured potato growth variables are likely to improve tuber yield. A study to establish the associations amongst the growth and yield parameters in each WWC and SF mix ratio is recommended. Hammed et al. [53] showed that different organic fertilizer formulations can influence the correlation between agronomic parameters differently.

4 Conclusion

In this study, co-application of WWC and SF has shown promising results in enhancing cob length, cob weight, grain weight per cob, grain number per cob and 1000-SW relative to the untreated control. In most instances, the increase in the measured yield parameters was quantitatively higher in treatment with the 50:50 WWC-SF mix ratio than in other treatments. The differences in compost types had insignificant influence on growth and yield parameters. This suggests that the addition of EM inoculant during composting of winery solid waste does not influence the quality of the WWC. Long-term field trials are recommended to assess the maize response to the co-application of WWC and SF under diverse soil and climatic conditions.

Author contributions All authors contributed to the study conception and design. Data collection and analysis were performed by [M.M.M.]. The first draft of the manuscript was written by [M.M.M.]. [O.O.B.], [A.R.M.] and [F.R.K.] reviewed the manuscript. All authors approved the final manuscript.

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Data availability All data generated or analyzed during this study are included in this published article.

Declarations

Ethics approval and consent to participate The experimental methods followed to conduct this research work were approved by the North-West University Research Ethics Regulatory Committee (Ethics number: NWU-00716-18-A9). Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the North-West University or the Agricultural Research Council of South Africa.

Competing interests The authors declare no competing interests.

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