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Enhancing maize productivity with compost manure and planting pits in the semi-arid region of Zimbabwe

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Abstract

Smallholder farmers in semi-arid areas depend on rainfed agriculture, which is limited by low total rainfall received, uneven distribution, and soil infertility. There is need for smallholder farmers in semi-arid areas to adopt the use of organic amendments. The objective of the study was to assess the combined effects of compost, tillage practice, and maize variety on grain yield, agronomic efficiency (AE), and nitrogen use efficiency (NUE) in semi-arid Zimbabwe. The experiment was laid in a randomised complete block design (RCBD) with treatments arranged in split plot. The experiment used conservation tillage as the main plot factor at three levels (planting pit (PP), mulched planting pit (MPP), and conventional tillage (CT) as a control). Compost manure was used as a sub-plot factor at three levels (0, 2.5, and 5 t ha^{-1}) and maize variety as a sub-sub plot factor at two levels (SC419 and SC555). Interactive effects of 5t ha^{-1} compost, MPP, and SC417 had the highest grain yield of 7109.9kg ha^{-1} which was significant when compared with other treatments under CT and PP. Increasing application rate of compost enhance AE which was significant ($p < 0.05$) when compared to treatments under MPP which had highest AE of 1.18kg kg^{-1} during a wetter 2024/25 season. Furthermore, NUE was also influenced significantly with use of 5t ha^{-1} compost, MPP, and SC419 during 2024/25 cropping season showing a highest value of 47.38kg kg^{-1}. Smallholder farmers are recommended to adopt 5t ha^{-1} compost, MPP, and SC419 to increase food security, AE, and NUE.

Introduction

Low crop productivity in rain-fed agriculture has been caused by inadequate application of nutrient sources, water stress due to low and erratic rainfall, and poor farming methods such as monoculture (Musafiri et al., 2022; Kugedera & Kokerai, 2025b). These constraints are becoming increasingly prevalent in semi-arid areas due to high cost of mineral fertiliser, inadequate application of nutrients, and low adoption of soil and water conservation techniques. These constraints are also influenced by a high population, which allows people to use agricultural intensification methods that contribute to land degradation (Mesele et al., 2025; Cosmas et al., 2026). There is a need for farmers in semi-arid areas to adopt soil and water conservation techniques which improve soil fertility, soil water content, and food production.

Many smallholder farmers in semi-arid areas depends on rain-fed agriculture, which is constrained by low, and unreliable rainfall that is unevenly distributed (Bogale et al., 2025; Kugedera & Kokerai, 2025c). This significantly lower soil moisture, and cause poor nutrient absorption in the soil. Maize grain yield realized by smallholder farmers are very low, less than 1000 kg $ha^{-1,}$ with many farmers owning ≤2ha. The current trends of maize grain yield harvested by smallholder farmers in semi-arid areas are declining, causing many families to suffer food insecurity (Muoni et al., 2025). To boost maize grain yield, farmers in semi-arid areas of Zimbabwe must adopt the use of planting pits (*Pfumvudza*) and organic nutrient sources such as compost manure that can be easily prepared. Compost manure is one of the most important nutrient sources which is prepared using residues of various crops, with the best

made from legumes such as ground nuts and field beans (Bai et al., 2025; Alface et al., 2026). Additionally, compost manure increases soil organic carbon, structure, lower bulk density, and improves crop yields. Nutrient mineralization is increased with the application of compost manure due to an increase in microbial activities (Basir et al., 2025; Feyanbule et al., 2025a).

farmers in low rainfall areas can conserve moisture in their fields using planting pits which has the capacity to reduce surface runoff, soil erosion, and increase infiltration of water. Planting pits have the potential to store soil moisture content for three weeks during dry spell, reduce leaching, and increase soil water in the plant root zone (Getare et al., 2021; Kugedera, 2022; Kebenei et al., 2023). Furthermore, planting pits alone cannot increase grain yield significantly especially in sandy soils. There is need to integrate compost manure with planting pits to enhance soil fertility and water content in the soil simultaneously. This can be a better option for smallholder farmers to improve soil nutrient availability, reduce water stress, and enhance maize grain yield in semi-arid areas of Zimbabwe. This create a positive synergistic association that allow farmers to apply small quantities of nutrient sources in each planting pit but being enough to support the crop up to maturity (Kimaru-Muchai et al., 2021). The objective of the study was to assess the integrated effects of compost manure and planting pits on maize productivity under a smallholder farming environment in the semi-arid area of Zimbabwe. This study was based on the following hypothesis: (i) compost manure and planting pits have significant effects on maize grain yields under smallholder farming environment in semi-arid area of Zimbabwe; (ii) compost manure and planting pits have significant effects on agronomic use efficiency (AE) under maize in semi-arid area of Zimbabwe and (iii) compost manure and planting pits have significant effects on in semi-arid area of Zimbabwe.

Materials and methods

Study site

The experiment was done in a smallholder farming area located in ward 7 (20º13.406 S and 30º28.552' E, 880masl) of Chivi district in Zimbabwe. The study area is in agroecological zone IV that is characterized with low and erratic rainfall. The study area is moderately hot with high temperatures (30–35°C) and a minimum of 18°C. Significant cold temperatures were as low as 5°C that were experienced in June and July with chances of extending to mid-August. Smallholder farmers in the experimental areas mainly depend on rain-fed agriculture, growing crops such as maize (*Zea mays*), sorghum (*Sorghum bicolor*), groundnuts (*Arachis hypogea*) and babaranuts. Livestock production was also carried out with farmers rearing cattle, goat, donkeys, poultry and few farmers are on rabbit production.

Rainfall

The area received rainfall from mid-November to the end of April, with low chances of rainfall in May. The rainfall pattern is monomodal, with high rainfall received in mid-January to February in some seasons.

During the 2022/23 cropping season, mid-season dry spells were more than in the previous season, with the longest experienced from 29 December 2022 to 16 January 2023. The season received an average of 425 mm, with more rainfall received in the month of February. A total of 346mm was received during the 2023/24 cropping season, and the season was associated with long, frequent mid-season dry spells, with the longest reported from 22 January to 26 February 2024. Furthermore, a total of 596mm was received during the 2024/25 cropping season, with the highest rainfall of 245mm received from 3 January to 15 February 2025.

Soil sampling and analysis

A zig-zag soil sampling technique was used to obtain fifteen soil samples before planting during the 2022/23 to 2024/25 cropping season from a depth of 0–40 cm. All collected samples were mixed thoroughly in a plastic bucket, shade dried, and sieved through a 2mm sieve to remove stones, and a composite sample (1 kg) was produced for testing. Soil pH was determined using the Calcium chloride method ($CaCl_2$) and the Bouyoucos hydrometer method to determine soil texture (F. N. Kubiku et al., 2022). The Oslen method was used to determine soil organic carbon and available phosphorus (Kugedera et al., 2023). An atomic absorption spectrophotometer was used to determine exchangeable bases (Chiturike et al., 2025).

Research materials

The study used two maize varieties, which were indicated to be suitable for semi-arid areas receiving rainfall less than 650 mm per annum. The two varieties (SC419 and SC555) have a maturity time of 128 days and 135 days, respectively. The varieties have a yield potential of 14.7t ha^{-1} and 13.8t ha^{-1}, respectively. Experimental packets were obtained from Seed-Co Zimbabwe. The two varieties were grown on one site at one of the farmers' plots. Compost manure used in the experiment was prepared five months before the experiment using maize, groundnuts, and velvet bean residues. It had the following properties summarized in Table 1.

Table 1
Chemical properties of compost used in the experiment.

Treatments	pH	N (g kg^{-1})	P (g kg^{-1})	Mg (g kg^{-1})	Ca (g kg^{-1})	K (g kg^{-1})	C (g kg^{-1})	Bulk density (g cm^{-3})
Compost	6.2	25	14	3.9	22.5	20	382.6	0.78

Experimental design and treatments

The experiment was carried out using a randomised complete block design (RCBD) with treatments arranged in split plot. The experiment used conservation tillage as the main plot factor at three levels

(planting pit (PP), mulched planting pit (MPP), and conventional tillage (CT) as a control). Compost manure was used as a sub-plot factor at three levels (0, 2.5, and 5 t ha^{-1}) and maize variety as a sub-sub plot factor at two levels (SC419 and SC555). Treatments were replicated three times to give a total of 54 treatment plots. Planting pits were prepared using a hand hoe to achieve a depth of 0.15 m and a breadth of 0.2 m. Mulched planting pits (MPP) were prepared in the same way as PP, but the only difference was mulching, which was applied two days after planting. Decomposed compost manure was applied in all plots using 0, 2.5, and 5 t ha^{-1} in September 2022 prior to the planting season. The study used these rates, which are similar to rates applied using cattle manure by smallholder farmers in the study area. Each main plot was measuring 12 m long by 8 m wide, with sub-plot factors measuring 4 m by 2m, and a spacing of 0.5 m was left between treatments. Planting stations were spaced at 50 cm in rows by 75 cm between rows. The planting dates were as follows: 17 November 2022, 21 December 2023, and 21 November 2024 for 2022/23, 2023/24, and 2024/25 cropping seasons, respectively. Three seeds were sown at each planting station and thinned to two at day 14 after emergence to achieve a plant population of 53 333 plant ha^{-1}. Ammonium nitrate (34.5% N) was applied in all plots at a rate of 150 kg ha^{-1} in two splits at 75 kg ha^{-1} after 28 and 56 days from emergence.

Data collection

Data collected was based on maize grain and stover yield, and nitrogen use efficiency. Maize grain yield was determined by harvesting maize cobs from a net plot area of 6 m^2 when the grain attain moisture content of 13%. Maize cobs were threshed using solar powered maize sheller and weighed after manual winnowing using a digital balance. Maize stover was cut into smaller pieces and weighed using a digital scale per treatment and its replicates. Agronomic use efficiency was determined using the following Eq. 1. Nitrogen use efficiency (NUE) was determined using Eq. 2.

Agronomic use efficiency (AE) = $\frac{\text{Grain yield of fertilised plot (kg)} - \text{grain yield in control plot(kg)}}{Amount\ of\ compost\ applied\ (kg)}$ (Gram et al., 2020)---------- Eq. 1.

Nitrogen use efficiency (NUE) = $\frac{\text{Grain yield of fertilised plot (kg)} - \text{grain yield in control plot(kg)}}{Amount\ of\ N\ applied\ (kg)}$ (Gram et al., 2020)---------- Eq. 2.

Data analysis

Collected data on maize yields and NUE were subjected to analysis of variance (ANOVA) using GenStat 14th edition statistical software. Means separation was done using Fisher's Least Significant Difference (LSD) at a 0.05 level of significance, where P-values were significant. The study used a general statistical model for split-plot below:

$$Y_{ijk} = \mu + ß_i + T_{j(i)} + \text{1}_{j(i)} + C_{k(i)} + TC_{jk(i)} + ßTC_{ijk} + \text{2}_{jk(i)}$$

Where $\mathbf{Y_{ijk}}$ is the response variable to be analysed (maize yield, AE and NUE); **μ** is the overall mean; $\mathbf{ß_i}$ is the effect of the i^{th} variety (block) and i-stands for 1, 2, 3 (fixed effect); $\mathbf{T_{j(i)}}$ is the effects of the j^{th} tillage practice within the i^{th} block and j stands for 1, 2 and 3 where 1 stands for CT, 2 stands for PP and 3 stands for MPP; $\mathbf{1_{j(i)}}$ is the effect of whole plot error (block x R); $\mathbf{C_{k(i)}}$ is the fixed effect of the k^{th} compost manure application rate within the j^{th} R and i^{th} block while k stands for 0 kg, 2.5 and 5t ha^{-1}; $\mathbf{TC_{jk(i)}}$ is the interaction effects of j^{th} tillage practice and k^{th} compost application rate within the i^{th} block, $ßTC_{ijk}$ is the interaction of i^{th} variety, j^{th} tillage and k^{th} compost manure and $\mathbf{2_{jk(i)}}$ is the effect of sub-plot error (block x T x C).

Results

Soil characterisation

Initial soil characterisation from the experimental plots was classified as sandy clay loam with 470 g kg^{-1} sand, 190 g kg^{-1} silt, and 340 g kg^{-1} clay. Sampled soil had an average pH of 5.9, 0.35% SOC, 0.02% total nitrogen, 0.6 mg kg^{-1} exchangeable P, 1.2 $cmol_c$ kg^{-1} calcium, and 0.97 $cmol_c$ kg^{-1} magnesium, and a CEC of 13.2 $cmol_c$ kg^{-1}.

Effects of tillage practices, compost, and variety on maize grain yields

Maize grain yields were significantly affected ($p < 0.05$) by all treatment factors. Treatment plots where MPP were used had significantly higher ($p < 0.05$) maize grain yields compared with CT and PP (Table 2). Maize grain yields increased by 295 and 212 kg ha^{-1} for MPP and PP over CT respectively. Increasing application rate of compost manure showed significant effect ($p < 0.05$) on maize grain yields with 167.9% and 75.5% for 5 and 2.5 t ha^{-1} over treatments with 0 t ha^{-1} respectively. Maize variety, SC555 performed better than SC419 with an average grain yield of 117.5 kg ha^{-1} ($p < 0.05$). Furthermore, the effect of season was significant ($p < 0.05$) and highest grain yield of 2597.6kg ha^{-1} was observed from 2024/25 season, which was 1004.7kg ha^{-1}(63.1%), and 872.4kg ha^{-1}(50.6%) above 2023/24, and 2022/23, respectively.

Table 2
Effects of tillage practices, compost, variety, and season on maize grain yields

Treatment factors	Maize grain yield (kg ha^{-1})
Tillage practice	
CT	1589.9[c]
MPP	1884.9[a]
PP	1801.9[b]
LSD (0.05)	33.71
P-value	< 0.001
Compost (t ha^{-1})	
0	971[c]
2.5	1704.7[b]
5	2601.1[a]
LSD (0.05)	33.71
P-value	< 0.001
Variety	
SC419	1700.2[b]
SC555	1817.7[a]
LSD (0.05)	27.53
P-value	< 0.001
Season	
2022/23	1725.2[b]
2023/24	1592.9[c]
2024/25	2597.6[a]
LSD	27.53
P-value	< 0.001
CV (%)	2.8

Means in the same column followed by the same superscript are not significantly different at $p \leq 0.05$.

The interactive effects of tillage and compost manure were significant ($p < 0.05$). Specifically, MPP had the highest maize grain yield compared with CT and PP regardless of season and variety (Table 3). Additionally, the highest maize grain yield of 7109.9kg ha^{-1} was obtained from 5t ha^{-1} compost + MPP + SC419 which was 55% and 5.4% above same rate of compost, variety and season under CT and PP respectively. This highest yield from SC419 was 823.19kg ha^{-1} (13.1%) above same treatments under SC555. Results showed that variety SC419 performed above SC555 under all treatments integrated with all application rates of compost manure. Furthermore, results also showed that treatments without compost manure (0t ha^{-1}) integrated with MPP, PP, SC419 and SC555 showed no significant differences ($p > 0.05$) as shown in Table 3. Additionally, higher maize grain yield was also observed during 2024/25 cropping season regardless of variety, and application rate of compost manure.

Table 3
Interactive effects of tillage, compost, variety, and season on maize grain yield

Maize grain yield (kg ha^{-1})							
SC419					**SC555**		
Tillage practice	**Compost (t ha^{-1})**	**2022/23**	**2023/24**	**2024/25**	**2022/23**	**2023/24**	**2024/25**
CT	0	889.7^{a}	756.8^{a}	983.4^{a}	749.1^{a}	721.2^{a}	891.6^{a}
	2.5	2520.2^{c}	2387.4^{c}	2596.9^{d}	2100.7^{c}	1989.5^{d}	2215.9^{b}
	5	4360.8^{f}	3845.9^{f}	4586.9^{g}	3690.3^{f}	3234.7^{g}	3845.6^{e}
MPP	0	1010.7^{b}	845.3^{b}	1187.1^{c}	989.7^{b}	830.9^{c}	925.7^{a}
	2.5	3871.8^{e}	2696.2^{e}	3947.3^{f}	2672.2^{e}	2327.2^{f}	2985.2^{d}
	5	6772.3^{h}	5875.9^{h}	7109.9^{i}	5982.8^{h}	4910.1^{h}	6286.7^{g}
PP	0	1013.3^{b}	866.1^{b}	1100.4^{b}	964.9^{b}	796.9^{b}	905.7^{a}
	2.5	3722.3^{d}	2582.9^{d}	3802.8^{e}	2387.6^{d}	2092.6^{e}	2615.3^{c}
	5	6670^{g}	5748.4^{g}	6745.9^{h}	5242.7^{g}	4692.5^{i}	5434.7^{f}
LSD (0.05)		*58.9*	*72.3*	*69.5*	*58.9*	*72.3*	*69.5*
P-value		*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*
CV (%)		**2.8**	**1.2**	**3.9**	**2.8**	**1.2**	**3.9**

Means in the same column followed by the same superscript are not significantly different at $p \leq 0.05$.

Effects of tillage, compost, and maize variety on agronomic use efficiency (AE)

Agronomic use efficiency (AE) was affected by tillage practice, compost manure and maize variety significantly ($p < 0.05$). Treatments with MPP had the highest AE (0.348 kg kg^{-1}) which was 28.9% and 19.8% above CT and PP respectively. Additionally, agronomic use efficiency increased with application of compost manure, and showed significant differences between maize varieties ($p < 0.05$). Maize variety (SC555) had AE which was 8% greater than SC419 (Table 4). Specifically, AE was highest from 2024/25 cropping season, which was 28.3% and 17.9% above 2023/24 and 2022/23 cropping season respectively.

Table 4
Effects of tillage practices, compost, and variety on AE of maize

Treatment factors	AE (kg kg^{-1})
Tillage practice	
CT	0.273[c]
MPP	0.348[a]
PP	0.308[b]
LSD (0.05)	0.01252
P-value	< 0.001
Compost	
2.5	0.294[b]
5	0.32[a]
LSD (0.05)	0.01022
P-value	< 0.001
Variety	
SC419	0.297[b]
SC555	0.323[a]
LSD (0.05)	0.01022
P-value	< 0.001
Season	
2022/23	0.296[b]
2023/24	0.272[c]
2024/25	0.349[a]
LSD	0.01252
P-value	< 0.001
CV (%)	4.8

Means in the same column followed by the same superscript are not significantly different at $p \leq 0.05$.

The interactive effects of tillage practices, compost manure, and maize variety showed significant differences ($p < 0.05$) on AE. Results from this study showed that 5t ha^{-1} compost + MPP + SC419 had the highest AE of 1.18kg kg^{-1} which was 10.2% above same treatment under SC555. AE from CT and PP integrated with 5t ha^{-1} + SC419 were 63.9% and 4.4% below same treatment under MPP respectively (Table 5). Specifically, all treatments under CT had significantly lower ($p < 0.05$) regardless of season, and variety. Interactive effects of compost, tillage, and variety showed that AE increased with increase in compost rate regardless of seasons.

Table 5
Interactive effects of tillage practice, compost, and maize variety on AE

AE (kg kg^{-1})							
SC419					**SC555**		
Tillage practice	**Compost (t ha^{-1})**	**2022/23**	**2023/24**	**2024/25**	**2022/23**	**2023/24**	**2024/25**
CT	2.5	0.65^{e}	0.65^{e}	0.64^{f}	0.54^{f}	0.51^{d}	0.53^{f}
	5	0.69^{d}	0.62^{f}	0.72^{e}	0.59^{d}	0.5^{d}	0.59^{e}
MPP	2.5	1.14^{ab}	0.74^{c}	1.1^{c}	0.67^{c}	0.6^{c}	0.82^{c}
	5	1.15^{a}	1.01^{a}	1.18^{a}	0.999^{a}	0.82^{a}	1.07^{a}
PP	2.5	1.08^{c}	0.69^{d}	1.08^{d}	0.57^{e}	0.52^{d}	0.68^{d}
	5	1.13^{b}	0.98^{b}	1.13^{b}	0.86^{b}	0.78^{b}	0.91^{b}
LSD (0.05)		*0.0177*	*0.025*	*0.0194*	*0.0177*	*0.025*	*0.0194*
P-value		*< 0.001*	*< 0.001*	*< 0.001*	*< 0.001*	*0.001*	*< 0.001*
CV (%)		**1.1**	**2.1**	**4.6**	**1.1**	**2.1**	**4.6**

Means in the same column followed by the same superscript are not significantly different at $p \leq 0.05$.

Effects of tillage practices, compost manure, and maize variety on NUE

Nitrogen use efficiency (NUE) varied among tillage, compost manure and maize variety, showed significant differences ($p < 0.05$) between treatments. Furthermore, MPP had the highest NUE which was 5.3 kg kg^{-1} and 2.9 kg kg^{-1} above CT and PP respectively (Table 6). Moreover, increase in application rate of compost manure increased NUE significantly. Maize variety, SC555 had better NUE compared with SC419 which was also significant ($p < 0.05$). Furthermore, results showed that NUE varied with

season and was significant ($p < 0.05$) among seasons. Additionally, 2024/25 cropping season had the highest NUE which was 16.8% and 7.2% above 2023/24 and 2022/23 cropping seasons.

Table 6
Effects of tillage practices, compost, and maize variety on NUE

Treatment factors	NUE (kg kg^{-1})
Tillage practice	
CT	19.41[c]
MPP	24.71[a]
PP	21.81[b]
LSD (0.05)	0.882
P-value	< 0.001
Compost	
2.5	20.82[b]
5	23.13[a]
LSD (0.05)	0.721
P-value	< 0.001
Variety	
SC419	21.05[b]
SC555	22.9[a]
LSD (0.05)	0.721
P-value	< 0.001
Season	
2022/23	21.57[b]
2023/24	19.79[c]
2024/25	23.12[a]
LSD	0.882
P-value	< 0.001
CV (%)	4.8

Means in the same column followed by the same superscript are not significantly different at $p \leq 0.05$.

Nutrient use efficiency increased with application rate of compost manure, and varies when integrated with tillage practice and maize variety and was significant ($p < 0.05$). Results showed that combining MPP and 5 t ha^{-1} gave higher results across all cropping seasons and the results were significant ($p < 0.05$) when compared with other tillage practices under same compost rate. CT had the lowest NUE across all cropping seasons regardless of application rates of compost and maize variety. Additionally, combining 5t ha^{-1} + MPP + SC419 showed the highest NUE which was 4.8% and 64.3% above same compost rate and variety under PP and CT respectively (Table 7). Furthermore, results also showed that the use of CT + SC419 under all compost rates was eve gave lower NUE when compared to 2.5t ha^{-1} compost + MPP + SC419 across all seasons, with an average of 19.8% to 91.7% higher than NUE from CT + SC419. On the other hand, SC555 variety was significantly low when compared to SC419 combined compost manure and tillage practices (Table 7). In addition, results showed that NUE from SC555 under different compost rates, tillage practices and cropping seasons ranged from 20.1kg kg^{-1} to 42.9kg kg^{-1} which was significantly low when compared with 24.71kg kg^{-1} to 47.38kg kg^{-1} from SC419 combined with same treatments over same cropping seasons.

Table 7
Interaction effects of tillage practices, compost, and maize variety on NUE

NUE (kg kg^{-1})							
SC419					**SC555**		
Tillage practice	**Compost (t ha^{-1})**	**2022/23**	**2023/24**	**2024/25**	**2022/23**	**2023/24**	**2024/25**
CT	2.5	26.09^{c}	26.09^{d}	25.82^{e}	21.6^{e}	20.3^{d}	21.2^{f}
	5	27.77^{c}	24.71^{e}	28.83^{d}	23.5^{d}	20.1^{d}	23.6^{e}
MPP	2.5	45.78^{a}	29.61^{b}	44.16^{bc}	26.9^{c}	23.9^{c}	33^{c}
	5	46.09^{a}	40.24^{a}	47.38^{a}	39.9^{a}	32.6^{a}	42.9^{a}
PP	2.5	43.34^{b}	27.47^{c}	43.2^{c}	22.8^{d}	20.7^{d}	27.4^{d}
	5	45.25^{a}	39.06^{a}	45.2^{b}	34.2^{b}	31.2^{b}	36.2^{b}
LSD (0.05)		*1.72*	*1.15*	*1.5*	*1.72*	*1.15*	*1.5*
P-value		*< 0.05*	*< 0.001*	*< 0.001*	*< 0.001*	*< 0.05*	*< 0.001*
CV (%)		**2.8**	**1.2**	**3.9**	**2.8**	**1.2**	**3.9**

Discussion

Soil characterisation

Soil characteristics varies with season and application rates of compost manure together with tillage practice. This was because application of compost alone increase soil organic matter that decomposes to produce nutrients, colloidal materials that increase cementing of soil particles leading to better soil structure (Gao et al., 2025). In addition, compost manure has the potential of improving soil stability and aggregation that enhance soil porosity, reducing nutrient loss and increase its availability (Pattnaik et al., 2026). Furthermore, soil properties were changed significantly on mulched planting pits because the experiment used velvet bean (*Mucuna pruriens*) residues combined with grass for mulching. These residues quickly decompose and release nitrogen in the soil together with increasing soil total porosity. This retains water and prevent leaching (Sujatha et al., 2024). Additionally, conserved soil moisture also promote decomposition by microbes that have been increased by mulching.

Maize grain yield

Maize grain yield was influenced by compost manure with better yields obtained from 5t ha^{-1}. This was because increasing application rate of compost manure increased soil organic matter and carbon that promote a reduction in emission of greenhouse gases and increase nutrient availability (Manolikaki & Diamadopoulos, 2019). An increase in soil organic matter also improved water conservation and minimise leaching hence promote crop growth. Sandy loam soils in semi-arid areas are acidic and use of compost manure regulate pH and increase microbial activity that indirectly improve crop growth and yields (Basir et al., 2025; Alface et al., 2026; Feng et al., 2026). Furthermore, maize grain yield increased significantly from all treatments with mulched planting pits. This was stimulated by high soil water content that prevent water stress and increase nutrient absorption by plants (Kayusi et al., 2025; Sokombela, 2025). Planting pits collect and store water that can be used by plants for two to three weeks in absence of rainfall (Chilagane et al., 2020; Kimaru-Muchai et al., 2021). However, the addition of mulching material reduces surface evaporation, surface runoff, and increase infiltration which also contribute to lengthening of period from two-three weeks to four-five weeks. This reduce effects of mid-season dry spell and increase crop growth (Bekele & Chemeda, 2022; Kugedera & Kokerai, 2025b).

Maize variety SC419 performed better than SC555 in the experimental area because it is a drought tolerant variety and responds well to sandy loam soils. This was indicated by higher yields received regardless of compost rate, tillage practice, and cropping season. Drought tolerant crops have genes that allow them to thrive better under harsh environmental conditions that other varieties (Ajdig et al., 2025; Muoni et al., 2025). In addition, 2024/25 cropping season had higher maize grain yields compared with other seasons because higher total rainfall received was evenly distributed. Highest rainfall was received when maize crop was at its critical stages of tasselling and grain filling. This contributed to higher grain yield received. However, using compost, variety, or tillage practice alone does not significantly increase crop yields over many cropping seasons in semi-arid areas. Integrating them create a climate-smart agriculture option that improve food security in semi-arid areas associated with sandy loam soils (Kugedera & Kokerai, 2025a, 2025c). Combining benefits of compost and water conservation through planting pits had showed an improvement in maize grain yield to an extend that farmers can harvest 7109.9kg ha^{-1} when rainfall is good and 5875.9kg ha^{-1} when rainfall is between

400 and 450mm per annum. This showed that compost manure also improves water retention and use of mulched planting pits increase the benefits which translate to higher crop yield. These results were also in agreement with findings by Gao et al. (2025) and Kugedera & Kokerai (2025a) who reported that combining compost manure with water conservation increase crop yield. Sustainability in crop productivity is achieved through the use of organic amendments and water conservation techniques especially in semi-arid areas that receive low rainfall. Results obtained from this study were higher than those reported by Kugedera & Kokerai (2024) who reported the highest grain yield of 4936kg ha^{-1} using planting pits in Masvingo, Zimbabwe. This was because of differences in seasons, maize variety used (SC649) was not compatible to semi-arid areas due to short cropping season and low rainfall compared with SC419 and SC555 which are compatible to short seasons. The quality of compost manure used had better N content (62.5kg N ha^{-1} and 125kg N ha^{-1} for 2.5 and 5t ha^{-1} compost manure used) against the highest of 89.5kg N ha^{-1}.

Agronomic use efficiency (AE)

Application of compost manure increased AE with an increase in application rates. This may have been caused by improvements in soil physiochemical properties that enhance soil health and fertility. Compost manure increases AE by improving soil structure, availability of phosphorous and potassium, and water holding capacity that help in nutrient absorption (Basir et al., 2025). Combining compost with conservation tillage practices such as MPP optimise nutrient uptake and allow supply of nutrient throughout the cropping season due to slow release. Additionally, compost application lower soil bulk density, increase infiltration of water, and results in improved resilient soil for crop performance (Feyanbule et al., 2025b). So, when combining with planting pits that increase soil moisture, this enhances an increase in AE with its application. Furthermore, compost boost microbial biomass and its diversity leading to better nutrient cycling hence higher efficiencies achieved (Gao et al., 2025; Wang, Sale, et al., 2025). This become a key in achieving better agronomic efficiencies in semi-arid areas. Although some researchers indicated that increasing application of organic matter above 1000kg ha^{-1} decrease AE, this study showed evidence that an increase of organic manure application does not lower AE unless the rate is above the recommended level.

NUE

NUE increased with application of compost across all seasons and varieties although the increase differs. This has been mainly attributed to an increase in N released by decomposition of compost applied. Compost used in this study was prepared using crop velvet bean residues mixed with grass. This has the capacity of increasing N content due to biological nitrogen fixation done by velvet bean. This ultimately increased NUE in plots applied compost (Fu et al., 2025). Organic amendments have the capacity of increasing nitrogen availability and this increase NUE. Conservation tillage such as planting pits increase nutrient availability in the plant root zone, this increase absorption of nutrients by plants and facilitate higher NUE especially when optimum rates are used. This creates a positive synergistic association that allow plants to harvest all nitrogen made available (F. N. M. Kubiku et al., 2023). Water conservation techniques such as mulched planting pits have double benefits, that of water conservation

and nutrient cycling through decomposition of mulching material. Mulching has the potential of increasing NUE especially when legume residues were used as in this study (Wang, Chen, et al., 2025). Furthermore, maize variety SC419 had higher NUE because the variety is a short seasoned early maturity that have genetic make-up which allow higher NUE to achieve higher yield. So, combining water conservation tillage practices, early maturing variety, and better cropping season increase NUE especially in sandy loam soils.

Conclusion

Soil characteristics were improved with the application of compost manure although higher changes were reported from 5t ha^{-1} in sandy loam soils. This was advantageous to smallholder farmers in semi-arid areas because compost regulate soil pH, increase CEC, lower bulk density, and enhance water and nutrient retention. These benefits translate to improvements in soil health and fertility hence higher grain yields. Planting pits are key water conservation techniques as they reduce surface runoff, increase infiltration rates, and lower surface runoff. Mulching them creates an extra benefit that allow an increase in soil moisture content, lengthen cropping season, enhance soil organic matter, nutrient cycling, and soil structure that all help in crop performance, yield increments, and boost AE as well as NUE. Growing drought tolerant maize varieties as shown by SC419 has the potential to increase food security, and reduce hunger in semi-arid areas. Therefore, use of sole compost, mulched planting pits, and maize variety has no long term effects on grain yield, AE, and NUE but integrating them together enhance soil health, crop yields, AE, and NUE. This becomes a climate-smart option for smallholder farmers to improve maize productivity in semi-arid areas. Smallholder farmers are recommended to adopt 2.5t ha^{-1} compost + MPP +SC419 which is a cheap option that can provide them with enough for consumption (800kg yr^{-1} for a family of six) and sell the surplus of 1896-3147kg yr^{-1}. This combination allows them to keep extra food for two years without facing food insecurity.

Declarations

Declaration of interest

All authors declare no competing interest

Funding statement

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Author Contribution

Andrew Tapiwa Kugedera did conceptualisation, methodology, data collection, data analysis, writing first and final draft. Letticia Kudzai Kokerai did conceptualisation, data collection, editing first and final draft.

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