Poultry and cattle manure effects on sunflower performance, grain yield and selected soil properties in Limpopo Province, South Africa

The application of organic manures as alternatives to reduce the use of mineral fertilisers is considered a good agricultural practice for smallholder farmers. However, the effect of organic manure on soil properties and crop yield depends upon its application rate and its chemical composition. A field experiment was carried out during the 2013/2014 and 2014/2015 seasons at the University of Venda experimental farm (Limpopo Province, South Africa) to determine the effect of three organic manures (cattle, poultry and their 1:1 combination, 20 t/ha) on sunflower (*Helianthus annuus* L.) performance, grain yield and selected soil properties under rainfed conditions. Poultry manure produced the highest final infiltration rate and cumulative infiltration followed by cattle manure, their combination and the control in that order. Total nitrogen, calcium, and zinc were significantly different between treatments in the first season while potassium, sodium, and zinc were significantly different in the second season. Manure combination and poultry manure produced the highest organic carbon and available phosphorus, respectively, in both seasons compared to other treatments. Organic manure application had a significant ($p<0.05$) effect on dry matter, plant height and stem girth at all growth stages in the second cropping season but only in the flower bud stage for both parameters in the first season. Manure application in the second season resulted in an increase in the grain yield compared to the first season, except after application of poultry manure whereafter the grain yield decreased significantly by 168% from the first cropping season. The application of organic manure had a significant effect on sunflower grain yield, dry matter, head dry matter, plant height and stem girth throughout all growing stages in the second cropping season with poultry manure producing the best values.

Significance:

- Application of the three organic manures served as a good source of organic amendments for improvement of plant nutrients and selected soil properties.
- Based on the results of this study, poultry manure can be recommended as the first choice among the manure used for local smallholder farmers, especially under evenly distributed rainfall.

Introduction

Sunflower (*Helianthus annuus* L.) is the most important oilseed crop in South Africa and the third largest grain crop after maize (*Zea mays*) and wheat (*Triticum eastivum*).[1] Its seed is used in the manufacture of sunflower oil and oilcake for animal feed. It is a widely adapted crop which grows well under both light-textured and well-drained heavy-textured soils.[2] Furthermore, it can be produced under irrigation as well as under hot and dry climate, making the Limpopo Province an ideal production area.[3] In South Africa, sunflower has been produced mainly in commercial farms.[4] Its production by smallholder farmers in Limpopo Province has been relatively low, accounting for only 526 tons by year 2002, which makes it the lowest among the main field crops.[3] Declining soil fertility coupled with low and erratic rainfall are some of the problems contributing to low agricultural production in this Province. The Limpopo Province is one of the driest in South Africa with an average annual rainfall ranging from 400 mm to 600 mm.[3] Most soils in the Province in general, and in Vhembe District in particular, are fragile and low in fertility that needs to be sustained through application of fertilisers.[5] However, research has shown that the majority of smallholder farmers in the District cannot afford chemical fertilizers. Nevertheless, manure is affordable and readily available for use as a soil amendment.[5]

Although the benefits of animal manure are well documented in the literature, effects on sunflower have not been tested under the dryland conditions of the Limpopo Province. It is well established that animal manures improve crop yields through organic matter addition which in turn improves soil physical, chemical and biological properties and reduces soil erosion.[6] Research elsewhere has shown that the application of 10 t/ha and 20 t/ha farmyard manure improved sunflower grain yield.[7] Recently Materechera[8] reported improved aggregate stability, reduced soil strength and bulk density and increased bambara nut (*Voandzeia subterranean* L.) growth and yield after applying 5 t/ha of cattle manure on a hard setting and crusting chromic Luvisol in South Africa. Dunjana[9] observed in clayey soils that infiltration rates were increased by 30% with 25 t/ha cattle manure applications over control, while no changes in steady state infiltration rates were observed with manure application on sandy soils after 6 years.

It has also been observed that soil pH, organic matter, nitrogen, available phosphorus, exchangeable potassium, calcium and magnesium increased relative to control levels after the application of 15 t/ha and 30 t/ha and 10 t/ha and 20 t/ha of cattle and poultry manure, respectively.[10] In contrast, Dikinya and Mufwanzala[11] reported that poultry manure application, irrespective of the application rate, did not change the pH or acidity of the Luvic Calcisol. However, a substantial pH increase or change in pH with increasing application rate of poultry manure was observed in the case of Ferralic Arenosol and Vertic Luvisols, whereas the amount of exchangeable bases increased with increasing application rate for all the soil types. Therefore, the benefit of animal manure on soil fertility and crop yield depends on its composition, the soil type and the specific crop.

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In smallholder farming in South Africa, cattle, goats, sheep and chickens produce most of the animal manure.[12] The manure is collected, transported to the field and incorporated into the soil without composting[13], either because of a lack of knowledge or to reduce labour requirements[5,14]. Previous studies have indicated that less than 33% of smallholder farmers in the Vhembe District keep livestock (an average of 5 head of cattle, 10 goats and 8 chickens per household) and hence the quantity of manure was not enough.[5] Nevertheless, most farmers opted to mix the available manure to meet their manure requirements. A study by Aderinoye-Abdulwahab and Salami[14] reported that the most frequently used organic fertiliser by smallholder farmers is a combination of poultry and cattle manures (72.1%) as compared to poultry manure (29.8%) or cattle manure (25.9%) alone. Ibrahim and Fadni[15] reported that manure combination increased crop yield by 90% as compared to 70% and 50% of poultry and cattle manure, respectively. The practice of mixing different manure types has been reported elsewhere with similar result.[16-18]

Although the practice of mixing different organic manure types by smallholder farmers is common in most rural farming areas of South Africa, there has not been any agronomic evaluation of the practice. The aim of this study was to evaluate the application of three organic manures on sunflower performance and selected soil physical and chemical properties under rainfed conditions in the Limpopo Province. It was hypothesised that cattle manure, poultry manure and their combination would improve selected soil properties, leading to the improvement of sunflower performance and grain yield.

Materials and methods

Description of the study site

A field experiment was conducted during the 2013/2014 and 2014/2015 cropping seasons at the University of Venda experimental farm (22°58' S; 30°26' E) at Thohoyandou in the Limpopo Province of South Africa. The study site is 596 m above sea level and receives highly seasonal rainfall averaging 781 mm per annum. Most (85%) of the rainfall occurs between October and March (summer), coinciding with the highest evaporative demand, with an annual aridity index of 0.52, the area is considered borderline between semi-arid and sub-humid according to the UNESCO classification criterion.[19]

The soil at the experimental site has been described and is classified locally as Shortlands form[20] equivalent to Rhodic Ferralsol[21]. The soil is deep (>1200 mm), red (10YR3/3), moist clay with a weak angular and subangular blocky structure and well drained with a pH (H_2O) of 5.7.

Organic manure sources and application

The organic manure sources were cattle manure (obtained from a nearby smallholder farmer), poultry manure (obtained from the University of Venda broiler house), and the combination of the two manures at a ratio of 1:1 on dry weight basis (Table 2). The cattle manure was collected from the cattle pens from a depth of 0–10 cm using a spade and transported to the field. Poultry manure was collected from the broiler house into 50-kg bags and transported to the field. Both cattle and poultry manures were applied before composting them to mimic the local farming practice. Before applying the manure to the soil, it was homogenised by thoroughly mixing it and the larger particles were reduced manually. Manure was applied by evenly broadcasting and then thoroughly incorporated it into the experimental plots using a hand hoe to an approximate depth of 10 cm. Manure was applied 21 days before planting to allow sufficient time for it to react with the soil.[22,23] Each manure type and the combination was applied at a rate of 20 t/ha, except for control plots where no manure was applied.

Before application, the two organic manure sources were analysed to determine pH, organic matter content, total nitrogen, extractable phosphorus and zinc, exchangeable calcium, magnesium, sodium and potassium, and cation exchange capacity.

Land preparation and experimental layout

The experimental site was ploughed using a disc plough at the beginning of the first cropping season only. Ploughing was followed by manual seed-bed preparation and plot demarcation before planting. Land preparation for the second cropping season for each plot was done manually in order to retain the demarcation of the previous season. The field layout was a randomised complete block design totalling 16 plots with individual plots measuring 36 m^2 (6 x 6 m). The plots were separated by 1 m to avoid encroachment of manure, giving a total experimental site area of 841 m^2. Four treatments were applied (control, poultry manure, cattle manure and the 1:1 combination of manures) with four replicates of each.

A landrace sunflower seed collected from local smallholder farmers was planted. Two seeds were planted per hole at a 0.3-m intra-row spacing and 1-m inter-row spacing and at an approximate depth of 2.5 cm. Planting was done on 8 December 2013 and 28 November 2014 for the first and second cropping seasons, respectively. The seedlings were thinned to one plant per hole after 2 weeks of emergence. The plant density after thinning was approximately 33 333 plants/ha. Weeds were controlled manually.

Soil sampling and analysis

Each season before manure application and planting, three soil samples were randomly collected at a depth of 0–20 cm using a soil auger. Samples were bulked, dried, sieved (2 mm) and stored in a laboratory plastic bag for subsequent physical and chemical analyses. At the end of each cropping season, representative soil samples from each plot at the same depth were collected for analysis.

Bulk density was determined using the core method.[24] Particle size distribution analysis was carried out by Bouyoucos hydrometer method[25] using sodium hexametaphosphate (calgon) as the dispersant. Infiltration rate in each plot was determined using a double ring infiltrometer method following the procedure described in Bouwer[26]. The double ring infiltrometer consisted of two pairs of inner and outer rings, a driving plate, an impact absorbing hammer, measuring bridge and measuring rods with float. The inner ring measured 28 cm x 0.5 cm x 25 cm (diameter x thickness x height) while the outer ring measured 53 cm x 0.5 cm x 25 cm.

Soil pH was measured (in supernatant suspension of a 1:2.5 soil:water) using a pH/electrical conductivity/total dissolved solids multimeter probe.[27] Total nitrogen was determined by the micro-Kjeldahl method.[28] Available phosphorus was determined by the Bray 1 method.[29] Zinc was extracted with 0.1 M HCL and determined by atomic absorption spectrometry. Potassium, calcium, magnesium and sodium extractions were done using 1 M ammonium acetate at a pH of 7 and exchangeable cations were determined using atomic absorption spectrometry. Organic carbon was determined by the Walkley–Black procedure.[30]

Plant sampling and measurements

Plant samples were collected for above-ground dry matter at flower bud, flowering and maturity stages, for both growing seasons. Plants in the second outer rows were sampled over a row length of 1 m starting at 0.3 m from each row. Plant samples were partitioned into leaves, heads and stems, and thereafter dry matter was determined and expressed in kilograms per hectare. Plant height and stem girth at flower bud stage, flowering stage and grain maturity stage were measured from two marked plants (second and fourth plants) from each of the two central rows and an average was obtained. A total number of four plants per plot were used to determine the plant height and stem girth. The plant height was measured from the base of the plant to the tip of the top-most leaf.

At physiological maturity, two middle rows were harvested for yield component determination. All sunflower heads were then measured for head diameter (cm), head dry matter (g/head) and the weight of 100 seeds. Grain yield was determined after threshing. Seeds were dried at 65 °C in the oven for 24 h and seed weight adjusted to 13% moisture content.

Meteorological data were recorded in both cropping seasons by an automatic weather station located approximately 60 m from the experimental site. Precipitation was measured using three standard rain gauges installed on the experimental site and recorded as the average of three rain gauges.

Table 1: Pre-cropping selected surface soil properties

Soil physical properties				Soil chemical properties									
Particle size (%)			Bulk density (g/cm^3)	pH (H_2O)	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (mg/kg)	Potassium (cmol (+)/kg)	Calcium (cmol (+)/kg)	Magnesium (cmol (+)/kg)	Sodium (cmol (+)/kg)	Zinc (mg/kg)
Sand	Silt	Clay										
22	18	60	1.12	5.7	1.57	0.081	1.63	0.54	6.82	2.41	0.12	2.60

Table 2: Chemical properties of the organic manures used

Organic manure sources	pH (H_2O)	Total carbon (%)	Total nitrogen (%)	Phosphorus (g/kg)	Potassium (g/kg)	Sodium (g/kg)	Calcium (g/kg)	Magnesium (g/kg)	Carbon:nitrogen ratio
Cattle manure	8.2	27	1.96	3.37	22.54	2.94	15.53	7.98	14:1
Poultry manure	7.0	31.9	1.61	9.68	11.21	2.18	90.59	6.58	20:1

Statistical analysis

Data collected were analysed using an analysis of variance for a randomised complete block design using IBM SPSS version 20.[31] Due to seasonal variability encountered during the two cropping seasons, particularly in terms of rainfall, further analysis was performed on two factors, namely cropping season and organic manure, and their interaction. The differences between the treatment means were separated using the least significant difference procedure.

Results

Pre-cropping selected surface soil properties

The soil was generally acidic (pH=5.7), dominated by clay with a low bulk density (1.12 g/cm^3), high in clay content (average of 60.5%), and had more calcium than other major nutrients, followed by magnesium, potassium and sodium, in that order (Table 1).

Chemical properties of the organic manure

Table 2 shows the results of the organic manure analysis. The pH of poultry manure was neutral, whereas cattle manure was slightly alkaline. Organic carbon content was higher in poultry manure than in cattle manure, whereas total nitrogen content was higher in cattle manure than in poultry manure (Table 2). Phosphorus content was about three-fold higher in poultry manure than in cattle manure. Potassium concentration was twice as high in cattle manure than in poultry manure. Calcium content of poultry manure was six times higher than that of cattle manure, while magnesium content of the two manures were similar (Table 2). The C/N ratio of poultry manure was higher than that of cattle manure (Table 2).

Climatic conditions

Ambient temperature was generally similar in both cropping seasons, while rainfall varied between the two seasons (Table 3). The total rainfall received in the first cropping season was about three-times higher than that in the second cropping season. Temperature was not different between the two cropping seasons, with maximum temperature slightly higher in the second cropping season. The mean maximum temperature (T_{max}) was about 30 °C while the mean minimum temperature (T_{min}) was about 20 °C during the cropping period (Table 3).

The highest rainfall received in the 2013/2014 season was in January (458 mm) when 37% (171 mm) of rainfall was received in 1 day. Unlike in January, rainfall in February was evenly distributed throughout the month with nearly the same number of rainy days between cropping seasons (Table 3). The month of March had a total rainfall of 192 mm with 99% (190.5 mm) of this rainfall occurring within the first 13 days of the month. Most of the rainfall in the second season occurred in December, with frequent rainfall occurring at the middle and towards the end of the month.

Table 3: Summary of monthly meteorological data during 2013/2014 and 2014/2015 cropping seasons

Month	Maximum temperature	Minimum temperature	Total rainfall (mm)	Rainy days
2013/2014				
December	26.74	18.59	269[a]	12.0
January	27.99	19.98	458	17.0
February	27.22	19.47	275	16.0
March	27.73	19.49	192[b]	12.0
Growing season	**27.42**	**19.38**	**1195**	**57.0**
2014/2015				
November	28.44	19.74	50[a]	3.0
December	30.49	18.99	313	16.0
January	31.20	19.40	56	12.0
February	32.94	19.22	16[b]	8.0
Growing season	**30.77**	**19.34**	**434.85**	**39.0**

[a]Rainfall received on or after planting; [b]rainfall received on or before harvest

Effect of organic manure on soil physical properties

Bulk density was not significantly different in the 2-year cropping period although the three manure treatments resulted in a slight decrease of less than 9.65% bulk density compared to the control (Table 4). Poultry manure produced the highest final infiltration rate (28.1 mm/h) and cumulative infiltration of all the treatments (Table 4). There was no significant increase between the addition of the combined manure and the control. The final infiltration rate after application of poultry manure and cattle manure increased by 67% and 43%, respectively, over that of the control.

Table 4: Effect of organic manure on surface soil physical properties

Treatment	Bulk density (g/cm^3)	Final infiltration rate (mm/h)	Cumulative infiltration (mm)
Control	1.14[a]	16.8[a]	101.3[a]
Cattle manure	1.07[a]	24.0[b]	151.2[b]
Poultry manure	1.03[a]	28.1[b]	185.8[b]
Combined manure	1.06[a]	17.4[a]	121.8[a]

Means in the same column followed by the same letter are not significantly different.

Effect of organic manure on surface soil chemical properties

Potassium and zinc were significantly different in the second cropping season (Table 5). A significant difference in pH was observed only in the second cropping season. Potassium was significantly different ($p<0.05$) among the treatments in the second cropping season, with the highest concentration obtained after the combination treatment.

Effect of organic manure on biomass and yield components

The highest dry matter yield was observed after application of poultry manure at the flower bud stage of the first (2571.4 kg/ha) and second (1141.7 kg/ha) cropping seasons (Table 6). In the flowering stage of the second cropping season, the highest value of dry matter (6127.4 kg/ha) was also observed under poultry manure treatment. Poultry manure increased ($p<0.05$) dry matter yield at flower bud stage by 1022.4 kg/ha and 617.1 kg/ha in the first and second cropping seasons, respectively, compared to the control.

Manure application had a significant effect ($p<0.05$) on plant height and stem girth in all growing stages in the second cropping season, whereas in the first cropping season, a significant effect was observed only in the flower bud stage for both parameters. Poultry manure produced the highest plant height in all growing stages for both cropping seasons. The manure combination (7.28 cm, 10.48 cm and 11.01 cm) and poultry manure (7.05 cm, 10.21 cm and 10.28 cm) produced the highest stem girth in all growing stages for the first and second cropping seasons, respectively.

The highest grain yield (3289.39 kg/ha) was recorded under poultry manure treatment in the first cropping season; this yield was six-fold higher than that of the control (Table 7). There was no statistically significant difference in yield after application of cattle manure and the combined manure (Table 7). Organic manure application in the second cropping season resulted in a higher grain yield compared to that of the

Table 5: Effect of organic manure on surface soil chemical properties for 2013/2014 and 2014/2015 cropping seasons

Treatment	pH (H_2O)	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (mg/kg)	Extractable cations (cmol(+)/kg)			Zinc (mg/kg)
					Potassium	Calcium	Magnesium	
First cropping season								
Control	5.91[a]	1.71[a]	0.045[a]	7.59[a]	0.4[a]	6.743[a]	2.162[a]	1.90[a]
Cattle manure	6.05[a]	1.47[a]	0.050[a]	9.25[a]	0.647[a]	8.462[a]	2.696[a]	3.34[a]
Poultry manure	5.94[a]	1.92[a]	0.042[a]	31[a]	0.643[a]	5.548[a]	1.937[a]	10.98[a]
Combined manure	5.97[a]	1.96[a]	0.037[a]	8.49[a]	0.572[a]	5.629[a]	2.119[a]	5.64[a]
Second cropping season								
Control	4.67[a]	1.50[a]	0.057[a]	1.94[a]	0.42[a]	7.17[a]	2.36[a]	1.94[b]
Cattle manure	5.88[b]	2.00[a]	0.065[a]	2.67[a]	1.07[b]	8.72[a]	2.98[a]	3.51[b]
Poultry manure	5.00[ab]	1.75[a]	0.057[a]	30.27[a]	0.98[b]	6.29[a]	2.23[a]	10.38[a]
Combined manure	4.26[a]	2.18[a]	0.078[a]	29.40[a]	1.42[b]	7.50[a]	3.10[a]	10.63[a]
Cropping season (CS)	$p<0.05$	ns	$p<0.05$	ns	$p<0.05$	ns	ns	ns
Organic manure (OM)	$p<0.05$	ns	ns	$p<0.05$	$p<0.05$	ns	ns	$p<0.05$
CS * OM	$p<0.05$	ns	ns	ns	ns	ns	ns	ns

Means in the same column followed by the same letter are not significant differently; ns, not significant ($p<0.05$).

Table 6: Effect of organic manure on dry matter, plant height and stem girth determination

	Dry matter (kg/ha)			Plant height (cm)			Stem girth (cm)		
Treatment	Flower bud	Flowering	Maturity	Flower bud	Flowering	Maturity	Flower bud	Flowering	Maturing
First cropping season									
Control	1549.0[b]	4285.1[a]	5152.8[a]	54.69[a]	184.63[a]	186.50[a]	4.51[b]	8.21[a]	8.45[a]
Cattle manure	2110.3[a]	6969.5[a]	7209.7[a]	83.06[b]	172.13[a]	183.81[a]	6.88[a]	10.09[a]	9.74[a]
Poultry manure	2571.4[a]	6515.0[a]	6955.6[a]	106.75[c]	204.25[a]	209.13[a]	7.24[a]	10.00[a]	10.49[a]
Combined manure	2485.4[a]	7446.4[a]	7275.5[a]	90.88[bc]	201.75[a]	205.69[a]	7.28[a]	10.48[a]	11.01[a]
Second cropping season									
Control	524.6[a]	2869.7[b]	3416.1[b]	39.31[b]	150.86[a]	152.75[a]	4.00[b]	6.19[a]	6.25[a]
Cattle manure	704.8[b]	5395.7[a]	8751.1[a]	90.75[a]	179.13[b]	182.06[b]	6.56[a]	9.56[b]	9.69[b]
Poultry manure	1141.7[c]	6127.4[a]	8408.9[a]	100.00[a]	198.31[c]	199.38[c]	7.05[a]	10.21[b]	10.28[b]
Combined manure	967.3[d]	5914.5[a]	9414.7[a]	88.63[a]	188.88[d]	189.75[d]	6.45[a]	8.56[c]	8.63[c]
Cropping season (CS)	$p<0.05$	$p<0.05$	ns	ns	$p<0.05$	$p<0.05$	ns	ns	$p<0.05$
Organic manure (OM)	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$	$p<0.05$
CS * OM	ns	ns	$p<0.05$	ns	ns	ns	ns	ns	ns

Means in the same column followed by the same letter are not significantly different; ns, not significant ($p<0.05$).

first cropping season, except after application of poultry manure which consequently decreased yield by 168% from the first cropping season.

Table 7: Grain yield, head diameter, head dry matter and 100-seed weight

Treatment	Grain yield (kg/ha)	Head diameter (cm)	Head dry matter (g/head)	100-seed weight (g)
First cropping season				
Control	582.47[a]	19.79[a]	27.38[a]	5.26[a]
Cattle manure	1173.20[b]	22.81[a]	42.63[b]	6.08[a]
Poultry manure	3289.39[c]	22.28[a]	49.27[c]	5.29[a]
Combined manure	1336.49[b]	20.53[a]	34.71[d]	5.55[a]
Second cropping season				
Control	968.35[a]	12.84[b]	12.06[b]	4.59[a]
Cattle manure	1646.14[b]	19.88[a]	27.32[a]	5.28[a]
Poultry manure	1227.75[a]	20.25[a]	29.28[a]	5.45[a]
Combined manure	1647.29[b]	20.50[a]	32.50[a]	5.24[a]
Cropping season (CS)	ns	$p < 0.05$	$p < 0.05$	ns
Organic manure (OM)	ns	$p < 0.05$	$p < 0.05$	ns
CS * OM	ns	$p < 0.05$	$p < 0.05$	ns

Means in the same column followed by the same letter are not significantly different; ns, not significant ($p<0.05$).

Cattle manure produced the highest head diameter (22.81 cm) in the first cropping season whereas the combined manure produced the highest value (20.50 cm) in the second cropping season. There was a significant effect ($p<0.05$) on head dry matter in both cropping seasons. Poultry manure (49.27 g/head) and the combined manure (32.50 g/head) produced the highest head dry matter values in the first and second cropping seasons, respectively. There was no statistical difference among the treatments for 100-seed weight.

Discussion

Effect of organic manure on soil physical properties

Manure application did not significantly lower soil bulk density in comparison with the control treatment (Table 4). The results are in contrast to the findings by Ojeniyi et al.[32] who observed a significant decrease in bulk density at 0–15 cm depth under 10 t/ha poultry manure application in a 3-year field experiment on an Alfisol. Lack of significant difference in bulk density among treatments could be attributed to the short duration of the experiment with organic manure being less effective in altering bulk density significantly. Slow alteration of bulk density after long-term application of organic manure was reported by Cebula[33] and Brar et al.[34] Tadesse et al.[35] reported no difference in bulk density at a soil depth of 0–20 cm after applying 7.5 t/ha and 15 t/ha of cattle manure for two cropping seasons, with 15 t/ha rates recording the lowest bulk density value on a Vertisol of 71.25% clay content. The lower values of bulk density for this study could be due to microorganisms burrowing in the soil and also large opened cracks which were observed during the cropping seasons. Ibrahim and Fadni[15] also reported no significant difference in bulk density after applying 10 t/ha of cattle manure, poultry manure and the combined manure on a sandy soil, with cattle manure recording the lowest bulk density followed by poultry manure then the combined manure in both 0–20 cm and 20–40 cm soil depths.

Poultry manure, followed by cattle manure, produced the highest infiltration rate until a steady state was reached. This result is shown by a high final infiltration rate of 28.1 mm/h (Table 4). The increase in infiltration rate under poultry manure application may be due to a relatively low bulk density brought about by poultry manure application (Table 4) and high organic carbon in poultry manure (Table 2). However, there was no significant difference in final infiltration rates between cattle manure and poultry manure treatments. Similar to the findings of this study, Mubarak et al.[36] observed that there was no significant difference in infiltration rate among treatments after 10 t/ha of cattle manure and poultry manure was applied on a sandy soil. The poultry manure treatment produced the highest infiltration value of 185.8 mm compared to the control (101.3 mm) (Table 4), which could be attributed to its low bulk density. Application of cattle manure and the combined manure produced final infiltrations of 151.2 mm and 120 mm, respectively. This may indicate an additive effect of cattle manure as found by Rasoulzadeh and Yaghoubi[37] who reported that by applying cattle manure (at 0, 30 t/ha and 60 t/ha) on a sandy clay loam for 9 months, cumulative infiltration increased with the increasing rate.

Effect of organic manure on soil chemical properties

The pH was significantly different between the treatments in the second cropping season only. The highest pH was recorded under cattle manure treatment for both cropping seasons. This finding could be attributed to the high pH of the cattle manure itself. Azeez and Van Averbeke[38] reported a significant increase in pH after the application of cattle and goat manures as compared to that after application of poultry manure.

The pH was not significantly different between the treatments in the first cropping season, which is in agreement with the findings of Dikinya and Mufwanzala[11] and Magagula et al.[39] who found that, after one cropping season, the application of cattle manure and poultry manure did not significantly change the pH of the soils, irrespective of the application rate. The pH in the second cropping season slightly decreased from that of the first cropping season – a finding similar to that of Roy and Kashem[40] who reported a gradual decrease in soil pH with an increase in application period.

In agreement with the results obtained in this study, Ibrahim and Fadni[15] recorded higher organic carbon after treatment with the combined manure than after cattle manure and poultry manure treatments. An increased organic carbon under the application of organic manure compared to control was observed by Okonwu and Mensah[41] and Roy and Kashem[40]. These authors further observed that organic manure application increased organic carbon[40,41], available phosphorus and extractable zinc[41]. The organic carbon, available phosphorus and zinc were found to be higher in poultry manure treatment than other treatments.[41]

Cattle manure produced the highest values of total nitrogen in both cropping seasons, which may be due to the fact that the cattle manure used had a higher total nitrogen than the poultry manure did (Table 2). Application of organic manure significantly improved available phosphorus in both cropping seasons. Poultry manure produced the highest phosphorus in both cropping seasons of all the treatments (Table 5), which may be because the poultry manure applied had more phosphorus than the cattle manure (Table 2). Ullah et al.[42] and Magagula et al.[39] also reported a higher phosphorus under poultry manure treatments at 5 t/ha and 20 t/ha, respectively. Similarly to our findings, Ullah et al.[42] reported that cattle manure produced higher availability of potassium in the soil than poultry manure.

Effect of organic manure on sunflower biomass and yield

Application of organic manure had a significant effect ($p<0.05$) on dry matter yield at all stages in the second cropping season but only at flower bud stage in the first growing season. An increase in dry matter yield under application of poultry manure at flower bud and flowering stages was reported by Helmy and Ramadan[16]. The dry matter yield produced in the first cropping season in this study was higher than that obtained in the second cropping season at flower bud and flowering stages (Table 6). This observation may be a result of the amount of rainfall received – more rainfall was received during the two growing stages in the first cropping season than in the second cropping season (Table 3). This observation may also be a result of late sampling in the first cropping season (45 and 75 days after planting) compared to 42 and 71 days after planting for the second growing season. In contrast, the dry matter yields in the second cropping season were higher than those of the first cropping season at maturity stage except for control treatment (Table 6). This decrease in the dry matter yield in the first cropping season at maturity stage may be due to the excess rainfall experienced towards the end of the season that may have caused fungal diseases on plants as evidenced by plant wilt. Fungal disease is also shown by an average dry matter increase of 47.7% from flowering to maturity in the second cropping season in a period of 14 days, compared to 5.5% increases in the first cropping season in a period of 36 days. Adebayo et al.[43] observed that the values of growth parameters (dry matter weight, plant height and plant girth) obtained during a low rainfall season were generally higher than the values obtained during a high rainfall season as disease and pest infestation were very low during low rainfall.

Poultry manure produced the highest plant heights in both cropping seasons throughout all three growing stages (Table 6). A similar observation was reported by Adebayo et al.[43] The highest mean plant height (171.64 cm) of sunflower under 8 t/ha of poultry manure after 10 weeks of planting was reported by Wabekwa et al.[44] Poultry manure application also produced the highest sunflower stem girth in the second cropping season but only during flowering and maturity stages (Table 6). The manure combination (the combined manure) application produced the highest values of sunflower plant height and stem girth in the first cropping season throughout the three growing stages (Table 6). The highest values recorded after application of poultry manure could be attributed to the high amounts of primary (macro) nutrients (phosphorus and potassium) obtained (Table 2). These two primary nutrients are well known to be essential for improving the quality of grains, fruits and vegetables and for increasing water use efficiency, photosynthesis and disease resistance, and they also are essential for plant cell division and enlargement.

The application of organic manure had a significant effect ($p<0.05$) on the grain yield in both cropping seasons. Similarly to our findings, Munir et al.[45] recorded the highest grain yield under poultry manure application in the first cropping season. Cattle manure and the combined manure application produced statistically the same quantity of grain yield in both cropping seasons. Esmaeilian et al.[46] observed higher grain yield under cattle manure treatment, which yielded similar results to that after application of poultry manure. Rasool et al.[7] also observed a 15% increase in grain yield over control values after application of 20 t/ha cattle manure. Organic manure application in the second cropping season (low rainfall; Table 3) resulted in a higher grain yield than after the first cropping season, as was also previously reported by Adebayo et al.[43] However, poultry manure application in the second cropping season resulted in a significant decrease in grain yield by 2061.64 kg/ha (168%) from the first cropping season (Table 7). The decrease in yield after treatment with poultry manure was observed by a decrease in dry matter at the grain maturity stage of the second cropping season (Table 6). The significant decrease in grain yield observed under poultry manure application may be an indication that poultry manure has lower water retention capacity, as rainfall was lower in the second cropping season, therefore the crops may have experienced water stress, hence the lower grain yield. Similarly to our findings, Esmaeilian et al.[46] observed that the control treatment produced the lowest grain yield compared with cattle manure and poultry manure treatments.

Organic manure application had a significant effect ($p<0.05$) on head diameter in the second cropping season, in agreement with earlier findings by Esmaeilian et al.[46] The application of organic manure in the first cropping season produced the highest head diameter compared to that of the second cropping season for all treatments. Both cropping season and organic manure had a significant effect on head diameter. Organic manure contributed to a significant increase in head diameter over the control in the second cropping season compared to the first cropping season, supporting the findings of Wabekwa et al.[44] Cattle manure produced the highest head diameter (22.81 cm) in the first cropping season, as previously reported[46], whereas in the second cropping season, the combined manure produced the highest head diameter of 20.50 cm (Table 7). The lower values of head diameter and head dry matter recorded in the second growing season may be due to the low rainfall received in the second cropping season. The highest head dry matter value (49.27 g/head) was recorded by poultry manure application in the first cropping season compared to other treatments. In the second cropping season, the combined manure produced the highest value followed by poultry manure application. This implies that poultry manure application had an effect on head dry matter. There was an interaction between cropping season and organic manure. The 100-seed weight was not significantly affected by organic manure application in either cropping season, similarly to the results observed by Helmy and Ramadan[16].

Conclusions

Application of the three organic manures provided a good source of organic amendments for improvement of selected soil properties and plant nutrients. Application of poultry manure and cattle manure equally showed a significant influence on final infiltration rate and cumulative infiltration. Although not significant, organic manure application improved bulk density, with poultry manure treatment being the best among the treatments, followed by manure combination, cattle manure treatment and control, in that order. The manures produced a significant increase in pH, exchangeable potassium and zinc in the second cropping season. Exchangeable calcium increased by 20% and 14% under poultry manure treatment in the first and second cropping seasons, respectively. This increase may be attributable to a higher calcium content in poultry manure than cattle manure. Total nitrogen was not significantly affected by organic manure application.

Application of organic manure significantly increased dry matter accumulation, plant height and stem girth in all growing stages in the second cropping season with poultry manure producing the highest values. In the first cropping season, a significant effect was observed in the flower bud stages only. Sunflower grain yield and head dry matter were significantly affected by manure application in both cropping seasons, with the highest value recorded under poultry manure treatment in the first cropping season and under manure combination in the second cropping season. Sunflower head diameter was significantly increased in the second cropping season.

Based on the results of this study, poultry manure is recommended as the first choice among these manures for local smallholder farmers, especially under evenly distributed rainfall. Long-term studies are needed in order to conclusively evaluate the effects of organic manures on soil properties, as recommended in the literature review. It should, however, be noted that the results obtained in this study are valid only for the specified soil and climatic conditions.

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Authors' contributions

M.J.M.: Conceptualisation, methodology, data collection, sample analysis, validation, data curation, writing – the initial draft, writing – revisions, project leadership, project management, funding acquisition. J.M.: Validation, methodology, data curation, writing – revisions, student supervision, project leadership. J.J.O.O.: Validation, data curation, writing – revisions, student supervision.

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