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Effect of Poultry and Goat Manures on the Nutrient Content of *Sesamum alatum* Leafy Vegetables

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Abstract: *Sesamum alatum* Thonn. is one of the less-popular but nutritious leafy vegetables that is still collected from the wild or as weeds among crops in South Africa. The plant is also used in medicines and cosmetics in Africa and elsewhere. Despite its importance, the cultivation of *S. alatum* under different agronomic systems for improved harvestable yield and nutrient content is still lacking. The study aimed to determine the response of *S. alatum* nutrient content to the application of poultry and goat manures. Plants were grown in pots under rain-fed shade cloth conditions, with poultry and goat manures applied at 0, 1, 2, and 3 t ha⁻¹ each, and they were laid in a completely randomized design. Shoot tips were harvested at 60 days after planting and analyzed for nutrient content. Shoots contained better nutrients in *S. alatum* plants grown during the first than the second season, with minor exceptions. Poultry and goat manure application led to an increase in Ca, Mg, K, P, and micro-nutrients. Goat manure had potential to increase the nutrient content in *S. alatum* than poultry manure, although differences were not substantial. Therefore, both manures could be equally used to improve nutrient content of *S. alatum*.

Keywords: calcium; magnesium; phosphorus; potassium; copper; iron; manganese; sodium; zinc; wild leafy vegetables



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1. Introduction

Sesamum alatum Thonn., commonly known as winged-seed sesame, is a leafy vegetable that is collected from the wild in KwaZulu-Natal, South Africa [1] and other parts of the globe [2,3]. It is an erect, year-round, mucilaginous herbaceous plant [4]. In Africa and Asia, soft and immature leaves, shoots, pods, and seeds are cooked and eaten fresh or dried and added into soups, sauces, snacks and cakes [3–6]. *Sesamum alatum* has excellent amounts of proteins, carbohydrates, dietary fibre, fats, Ca, N, P, K, Mg, and other trace elements such as Cu, Fe, Mn, Na, and Zn, which compare well with *Amaranthus hybridus* [1,7]. It also contains essential antioxidant which can be linked to its use as an ayurvedic medicine against diseases such as, diarrhoea, intestinal disorders [4], and diabetes [8]. It is also used as an aphrodisiac for human and livestock fertility improvement [4]. Fresh leaves and seeds are valued for their oils and their mucilaginous substance that has qualities valued in hair shampoo, cloth washers, and hair conditioner [3].

Organic manures are organic residues of animal and plant by-products [9,10]. Small-scale farmers usually rely on organic manures due to high costs and less accessibility of inorganic manures [11–13], which includes animal manures, compost, and green manures [14]. Organic manures improve plant root rhizosphere conditions which enhance the

assimilation of nutrients from the soil [15], as well as the nutrient content of the plant itself [12,16].

Applications of 2.5–6 t ha⁻¹ poultry manure cause an increase in the Ca, Mg [17], ash, fats, N, P, and protein contents in *S. indicum* leaves [18]. The ash, moisture content, proteins, carbohydrates, fibre, fat, N, P, and K in *C. olitorious* leaves increase when poultry manure is applied at 1 and 2 t ha⁻¹ [12]. The increase in the ash, fat, and protein content was also noted in *Amaranthus caudatus* and *A. cruentus* when poultry manure was applied [19]. Further, there is an increase in proximate and mineral contents with the application of 0.03 t ha⁻¹ of poultry manure on *A. cruentus*, *A. hybridus*, *A. deflexus*, and *A. spinosus* [20]. Goat manure applied at rates ranging from 2.5–13 t ha⁻¹ resulted in an increase in Ca, Mg, N, P, and K content in *Capsicum annuum* leaves [21]. Application of 8 t ha⁻¹ goat manure increases Ca, Cu, Fe, K, Mg, Mn, Na, P, and Zn content in *Cleome gynandra* shoots [22].

The nutrient content of *S. alatum* is only known for plants collected from the wild [1]. *Sesamum alatum* is one of the wild-collected leafy vegetables with no agronomic studies on its improvements under different soil fertilities using animal manure. To improve nutrient richness in *S. alatum*, a soil with necessary nutrients that will facilitate production and maintain or improve the crop nutrient content is a prerequisite. Therefore, the objective of this study was to examine the effect of poultry and goat manures on the nutrient content of *S. alatum*.

2. Materials and Methods

2.1. Study Site and Seed Sourcing

The study was conducted at the University of Zululand, KwaDlangezwa campus (28° 85' 24" S, 31° 84' 91" E), South Africa. Pot trials were conducted under a shade cloth with 600 µmol/m²/s light intensity (40% shade), over two summer seasons (September–December of 2018 and 2019). The agrometeorological data (temperature, rainfall, and relative humidity) for these seasons are presented in Table 1. Poultry and goat manure was obtained from the Agriculture Farm at the University of Zululand. Seeds were collected from Mseleni (27° 36' 71" S, 32° 53' 93" E), a rural village in the northern KwaZulu-Natal province.

Table 1. Meteorological data of the University of Zululand in 2018 and 2019 (South African Weather Services, Durban, 2020).

Month	Temperature (°C)				Rainfall (mm)		RH (%)	
	2018		2019		2018	2019	2018	2019
	Max.	Min.	Max.	Min.				
January	31.9	19.9	29.5	19.2	59.0	73.6	73	80
February	30.1	20.5	30.2	20.4	145.2	144.2	79	81
March	30.2	19.7	30.5	20.7	94.2	58.0	79	80
April	28.6	18.4	27.5	17.9	153.4	146.6	80	82
May	25.7	15.2	27.2	15.5	334.0	7.6	80	78
June	24.6	12.4	26.1	12.1	64.4	47.2	78	74
July	24.3	12.0	27.0	11.1	15.0	21.6	75	66
August	24.1	13.8	26.3	15.3	89.2	56.0	75	76
September	26.7	15.4	26.7	14.9	59.0	95.2	76	74
October	26.2	15.3	28.7	17.1	200.2	138.2	76	76
November	27.1	17.1	29.0	18.9	86.6	128.4	75	80
December	30.2	20.6	28.7	18.9	12.8	317.8	77	80
Mean	27.48	16.69	28.12	16.83	109.41	102.87	76.92	77.25

RH, relative humidity; max., maximum; min., minimum.

2.2. Experimental Design

River sand and loam soils collected at 30–60 cm soil depth were mixed at a ratio of 7:3 to make a sandy-loam mixture and used as a growth medium. Pots (20 L) were filled with 60 kg of growth medium, and manures were each applied at 0; 1; 2; and 3 t ha⁻¹,

mixed with the soil, irrigated to pot capacity, and left to incubate for 10 days under the shade cloth. Manure in tons per hectare of application rates was converted from grams per 20 kg of soil, which was equivalent to 2,000,000 kg of soil per hectare for a furrow slice. Pots were arranged in a completely randomized design of 2×4 factorial combinations. Sowing was carried out immediately after the 10-day soil–manure incubation period. Seeds were broadcasted in each pot and covered with a layer (1–2 mm) of sprinkled sand. At 60 days after planting, soft shoot tips (4–8 cm long) were harvested from five plants of each treatment for nutrient analyses. Shoots were thoroughly washed with distilled water, cut into small pieces and then dried in an oven at 60 °C until a constant dry weight was reached. Dried shoots were ground into powder, packaged in airtight plastic containers and stored in a fridge (−4 °C) for further analysis.

Five replications of each of the samples were analysed for their nutritive value in human food. Proximate and mineral analyses were conducted according to the Association of Official Analytical Chemists (AOAC) [23] and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) methods [24]. Fertility analysis of soil and manure physicochemical properties (Table 2) and nutrient concentration in shoots was conducted at the Department of Agriculture and Rural Development, Soil Fertility and Analytical Services section in KwaZulu-Natal.

Table 2. Available nutrient content, pH, organic carbon and total nitrogen of soil and manures used in this study.

Available Nutrients	Season One			Season Two		
	Soil	Manures		Soil	Manures	
	Sandy-Loam	Poultry	Goat	Sandy-Loam	Poultry	Goat
Organic carbon (%)	0.5	>6	>6	0.6	>6	>6
Nitrogen (%)	<0.05	>0.6	>0.6	<0.05	>0.6	>0.6
Phosphorus (mg L ^{−1})	5.00	890.00	350.00	15.00	940.00	500.00
Potassium (mg L ^{−1})	32.00	4076.00	2216.00	58.00	2656.00	12,696.00
Calcium (mg L ^{−1})	337.00	791.00	2966.00	340.00	1241.00	1773.00
Magnesium (mg L ^{−1})	112.00	574.00	857.00	94.00	997.00	857.00
Zinc (mg L ^{−1})	1.50	72.20	29.30	6.40	59.00	18.20
Manganese (mg L ^{−1})	26.00	62.00	25.00	31.00	37.00	10.00
Copper (mg L ^{−1})	0.80	4.90	0.90	3.70	4.20	0.80
pH (KCl)	4.68	7.70	7.19	4.63	7.06	7.54

2.3. Soil and Manure Analysis

Soil or manure samples were air-dried at room temperature, after which they were spread out in drying trays and air was forced over them. When dry, the samples were crushed between rubber belts on a soil or manure crusher and passed through a 1 mm sieve. Material coarser than 1 mm that cannot be crushed (such as stones, gravel, and concretions) were discarded. Samples were scooped into trays which each contained 11 PVC cups (capacity 70 mL); a tray was used for nine unknown samples, one standard sample (for quality control), and one blank. For operations such as dispensing and stirring and for quality control, batches of three trays (27 samples, three unknowns, and three blanks) were used. Multiple dispensers and diluter/dispensers were used to dispense aliquots of extractant or reagent to three samples at a time.

Soil or manure samples were analysed on a volume rather than a mass basis. To enable the conversion of the results to a mass basis, the mass of a 10 mL scoop of a dried and milled sample was measured and the calculated sample density was reported. For the determination of pH, 10 mL of soil or manure was scooped into sample cups. Then, 25 mL of 1 M KCl solution was added, and the suspension was stirred at 400 revolutions per minute (r.p.m.) for 5 min using a multiple stirrer. The suspension was allowed to stand for about 30 min, and the pH was measured using a gel-filled combination glass electrode while stirring. De-ionised water was substituted for the 1 M KCl solution if pH (water) was required.

Extractable (1 M KCl) calcium and magnesium: A total of 2.5 mL of soil or manure was scooped into sample cups. Then, 25 mL of 1 M KCl solution was added, and the suspension was stirred at 400 r.p.m. for 10 min using a multiple stirrer. The extracts were filtered using Whatman No.1 paper. A total of 5 mL of the filtrate was diluted with 20 mL of 0.0356 M SrCl₂, and Ca and Mg determined by atomic absorption. To determine extractable acidity, 10 mL of the filtrate was diluted with 10 mL of de-ionised water containing 2–4 drops of phenolphthalein and titrated with 0.005 M NaOH.

Extractable (Ambic-2) phosphorus, potassium, zinc, copper and manganese: The Ambic-2 extracting solution consisted of 0.25 M NH₄CO₃ + 0.01 M Na₂EDTA + 0.01 M NH₄F + 0.05 g L⁻¹ Superfloc (N100), adjusted to pH 8 with a concentrated ammonia solution. An amount of 25 mL of this solution was added to 2.5 mL soil, and the suspension was stirred at 400 r.p.m. for 10 min using a multiple stirrer. The extracts were filtered using Whatman No.1 paper. Phosphorus was determined on a 2 mL aliquot of filtrate using a modification of the Murphy and Riley [25] molybdenum blue procedure [26]. Potassium was determined by atomic absorption on a 5 mL aliquot of the filtrate after dilution with 20 mL de-ionised water. Zinc, Cu, and Mn were determined by atomic absorption on the remaining undiluted filtrate.

Estimation of organic matter by the Walkley–Black method: Organic matter was based on the Walkley–Black procedure [27], which measured the readily oxidizable organic carbon. The organic matter was oxidized by potassium dichromate in a sulphuric acid medium. The excess dichromate was determined by titration with standard ferrous sulphate solution.

2.4. Proximate Analysis

Shoots were examined for the protein, fibre and fat content from each treatment.

Crude proteins: Two grams of dried sample powder were weighed and introduced into a 650 mL digestion flask along with 10 mL of distilled water. A digestion tablet along with 20 mL of concentrated H₂O₄ was added to the flask to act as the solution catalyst. Boiling chips were added to the mixture and the digestion was given time until a colourless solution was obtained. The digestion solution was allowed to cool before it was diluted with distilled ammonia-free water up to 100 mL. The Kjeldahl flask was pre-washed using distilled water for use. A total of 10 mL of the digest's 100 mL solution was pipetted into a distillation flask with 90 mL of distilled water. Twenty millimetres of 40% NaOH were pipetted into the distillation flask. A 250 mL conical flask containing 10 mL boric acid solution along with some drops of the indicator was used. Ammonia was then purified from the solution. About 100 mL of ammonia was extracted from boric acid. After extraction, the 100 mL solution was titrated against 0.1 N HCl until a pink colour appeared. The titrated volume was then subtracted from the original sample's titrated volume. Values obtained from the above process were used to calculate the N content percentage of the sample using the formula:

$$\% \text{ Nitrogen} = \frac{\text{millimetre acid} \times \text{normality standard acid}}{\text{weight of the sample in grams}} \times 0.014 \times 100$$

The crude protein percentage was calculated by multiplying the nitrogen percentage by a conversion factor of 6.25.

Crude Fibre (Acid Detergent Fibre and Neutral Detergent Fibre): Crude fibre was estimated by 1.25% H₂SO₄ and 1.25% NaOH solutions. Ether extract residue was introduced into a digestion flask along with a 200 mL boiling H₂O₄ solution. Similarly, an anti-foaming agent was added and connected to the flask immediately with a condenser and heated for 30 min. After that time, the digestion flask was removed and filtered immediately for its content using linen cloth and then washed using boiling water till the acid was removed from the washings. After washing, the residue was again introduced into a flask containing 200 mL of boiling NaOH solution. The flask was then connected to a reflux condenser and heated for 30 min. After 30 min, the flask was removed, the precipitate content was filtered with a gooch crucible and then it was washed using boiling water. Filtered content was washed with 15 mL of 95% alcohol (ethanol) and it was dried along with the crucible at 110 °C

till a constant weight was achieved. The content and crucible were cooled in a desiccator and weighed. The crucible content was incinerated for 30 min in a furnace at 550 °C until the carbonaceous matter was consumed. It was cooled again in a desiccator and the final weight measurements were taken. The following formula was used to calculate crude fibre as the loss in weight:

$$\text{Crude fibre \%} = \frac{\text{wt. of dry crucible and sample} - \text{wt. of incinerated and ash}}{\text{sample weight}} \times 100$$

Crude fats: The amount of fat contained was determined using petroleum ether as a reagent. Firstly, the weight of the bottle and lid to be used were ensured to be stable and sterilized. This was carried out by placing the bottle and lid in an incubator at 105 °C for 12 h. About 100 g of the sample was weighed and wrapped using a paper filter. The wrapped sample was extracted using a thimble and then transferred into a Soxhlet filled with about 250 mL of petroleum ether and then heated. The Soxhlet apparatus was connected and placed in water to cool down and then heated again for 14 h at a heating rate of 150 drops/min. The solvent was completely evaporated using a vacuum condenser and incubated at 80–90 °C until the bottle became dry. The lid of the bottle was transferred to the desiccator for cooling and the dried content of the bottle was reweighed. The results were expressed in percentages using the formula:

$$\text{Fat (\%)} = \frac{\text{Weight of fat}}{\text{Weight of sample}} \times 100$$

2.5. Mineral Analysis

The mineral elements analysis of Ca, Cu, Fe, K, Mg, Mn, Na, P, and Zn in the samples were quantified in triplicate using ICP–OES [24]. The plant material samples were analysed using the batch-handling procedure as described by Manson and Roberts [24]. The samples were dried at 75 °C and sieved using a 0.84 mm sieve. The product after sieving was ash dried overnight at 450 °C and was then taken up to 1 M of HCl. The following elements: Ca, Cu, Fe, K, Mg, Mn, Na, P, and Zn were determined using ICP–OES.

2.6. Data Analysis

Data were subjected to analysis of variance (ANOVA) using the General Linear Model procedure of the Statistical Analysis System (SAS) the General Linear Model procedure [28]. Tukey's Studentized Range test (HSD) was used to compare treatment means at $p < 0.05$.

3. Results

3.1. Effect of Seasonal Variation on Nutrient Content

Plants that were grown in the first season had better macro- and micro-nutrient content than in the second season (Table 3). However, the exception was recorded in acid detergent fibre, which was greater in plants grown during the second than in the first season, as well as neutral detergent fibre and fats, where both had insignificant differences during both seasons.

Table 3. Effect of season as well as poultry and goat manure on *S. alatum* nutrient content.

Season		Macronutrients (%)						Micronutrients (ppm)							
		ADF	NDF	Ca	Mg	K	K/Ca + Mg	Fat	P	Protein	Cu	Fe	Mn	Na	Zn
One		20.34 ^b	29.39	0.91 ^a	0.54 ^a	2.96 ^a	0.80 ^a	3.98	0.29 ^a	36.76 ^a	11.48 ^a	399.00 ^a	64.48 ^a	1500.00 ^a	49.67 ^a
Two		22.51 ^a	30.11	0.68 ^b	0.38 ^b	2.00 ^b	0.76 ^b	3.39	0.25 ^b	34.12 ^b	7.52 ^b	198.33 ^b	46.62 ^b	900.00 ^b	40.48 ^b
Significance		***	NS	***	***	***	***	NS	**	***	***	***	***	***	***
Manure (t ha ⁻¹)															
Control	0	22.57 ^a	30.75 ^a	0.35 ^c	0.20 ^e	1.06 ^d	0.80 ^{ab}	2.88 ^{ab}	0.08 ^d	36.09 ^a	5.00 ^c	253.00 ^{dc}	38.00 ^d	700.00 ^d	29.00 ^d
Poultry	1	20.96 ^{ab}	29.61 ^{ab}	1.01 ^a	0.58 ^{abc}	3.00 ^{ab}	0.78 ^{bc}	3.23 ^{ab}	0.33 ^{abc}	33.39 ^c	11.00 ^{ab}	307.67 ^{abc}	60.67 ^b	1300.00 ^{bc}	49.33 ^{ab}
	2	20.07 ^b	27.50 ^b	0.72 ^b	0.44 ^{bcd}	2.65 ^{abc}	0.76 ^c	2.03 ^b	0.27 ^{abc}	36.77 ^a	8.67 ^{bc}	269.17 ^{bcd}	52.00 ^{bc}	1100.00 ^c	45.83 ^{abc}
	3	21.11 ^{ab}	28.32 ^{ab}	0.67 ^b	0.36 ^{ed}	1.96 ^c	0.77 ^{bc}	3.56 ^{ab}	0.25 ^{bc}	35.91 ^a	8.50 ^{bc}	227.33 ^d	43.00 ^{cd}	1100.00 ^c	42.83 ^{bc}
Goat	1	21.68 ^{ab}	29.86 ^{ab}	1.08 ^a	0.59 ^{ab}	3.28 ^a	0.82 ^a	4.66 ^a	0.37 ^a	33.63 ^{bc}	13.67 ^a	352.50 ^a	91.50 ^a	1600.00 ^a	57.33 ^a
	2	21.20 ^{ab}	30.84 ^a	0.70 ^b	0.42 ^{cd}	2.23 ^{bc}	0.80 ^{ab}	4.78 ^a	0.22 ^c	36.69 ^a	5.67 ^c	349.00 ^a	48.17 ^{bcd}	1200.00 ^{bc}	36.00 ^{cd}
	3	22.37 ^{ab}	31.38 ^a	1.06 ^a	0.64 ^a	3.16 ^a	0.77 ^{bc}	4.65 ^a	0.35 ^{ab}	35.61 ^{ab}	14.00 ^a	332.00 ^{ab}	55.50 ^{bc}	1500.00 ^{ab}	55.17 ^{ab}
Significance		*	**	***	***	***	***	**	***	***	***	***	***	***	***

ADF, acid detergent fibre; NDF, neutral detergent fibre; NS, not significant. Different superscript letter(s) (a, b, c, d and e) within a column indicate differences between seasons as well as manure types and concentrations within each nutrient, in Tukey's Studentized Range (HSD) ($p < 0.05$). Significance level: NS, not significant; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

3.2. Macro-Nutrients

3.2.1. Acid Detergent Fibre and Neutral Detergent Fibre

Sesamum alatum control plants had more acid detergent fibre (ADF) content compared with 2 t ha^{-1} of poultry manure-treated plants (Table 3). Again, the variation in manure types and quantities did not affect the ADF concentration in *S. alatum* (Table 3). Neutral detergent fibre (NDF) was higher in plants that were treated with goat manure at rates $\geq 2 \text{ t ha}^{-1}$ than untreated plants (Table 3). The highest ADF content recorded in the control and in plants treated with 3 t ha^{-1} of poultry and goat manures in the first and second seasons, respectively, was similar to all other application rates except rates $\geq 2 \text{ t ha}^{-1}$ of poultry manure (Table 4). The highest NDF contents obtained in plants without manure application in season one were comparable to the NDF contents achieved with 1 t ha^{-1} of poultry manure and all goat manure rates (Table 4). The lower ADF and NDF values of control and treated *S. alatum* from the current study (Tables 3 and 4) than values recorded in untreated species in Sudan (ADF = 34.9%, NDF = 39.2%) [7] were probably caused by differences in the harvest stages, plants were analysed at the seedling stage (60 DAP) where in this study, but in the flowering stage in Sudan. This generally means that these leafy vegetables are easily palatable and digestible prior to flowering [7].

3.2.2. Calcium, Magnesium, and Potassium

Generally, the calcium, magnesium and potassium contents were better in plants from soils treated with poultry and goat manure than the controls (Table 3). The highest calcium content was recorded in 1 t ha^{-1} of poultry as well as 1 and 3 t ha^{-1} of goat manure-treated plants. The highest magnesium content in 3 t ha^{-1} of goat manure-treated plants was similar to that obtained in plants exposed to 1 t ha^{-1} of poultry and goat manures. Again, the highest potassium content in 1 and 3 t ha^{-1} of goat manure-treated plants was similar to that of 1 and 2 t ha^{-1} of poultry manure-treated plants (Table 3). The interaction between seasons and manures shows that 3 t ha^{-1} goat manure-treated plants had a greater calcium content than the control in both seasons and poultry manure rates that were $\geq 2 \text{ t ha}^{-1}$ as well as 2 t ha^{-1} of goat manure in season two (Table 4). Similarly, magnesium content was higher in plants that received 3 t ha^{-1} of goat manure but was only significantly different with rates of $\geq 2 \text{ t ha}^{-1}$ of poultry manure, 2 t ha^{-1} of goat manure in the second season and the control in each season (Table 4). The potassium content was better with the application of 2 t ha^{-1} of poultry manure than the control in season one. No variations were noted between type and rate of manure application in *Sesamum alatum* potassium content (Table 4). In season two, the potassium content obtained with poultry manure ($\geq 2 \text{ t ha}^{-1}$) and 2 t ha^{-1} of goat manure was comparable with the control. Further, the lower ($< 2 \text{ t ha}^{-1}$) rate of poultry manure was similar to 1 and 3 t ha^{-1} of goat manure in season two (Table 4).

The highest K/Ca + Mg content was recorded in 1 t ha^{-1} of goat manure-treated plants (Table 3). Manure and application rate variations showed that all levels of poultry manure-treated plants produced a lower K/Ca + Mg content than that of plants treated with goat manure, except in 3 t ha^{-1} (Table 3). Seasons and manure interaction show that the application of different manure types and quantities did not affect the K/Ca + Mg content in both seasons. Plants that received 2 t ha^{-1} of poultry manure in season two recorded the least K/Ca + Mg content, but levels were comparable with 3 t ha^{-1} of poultry manure and 2 t ha^{-1} of goat manure in the same season (Table 4).

Table 4. Interaction between season and manure on *Sesamum alatum* nutrient content.

Season × Manure (t ha ⁻¹)		Macronutrients (%)							Micronutrients (ppm)						
		ADF	NDF	Ca	Mg	K	K/Ca + Mg	Fat	P	Protein	Cu	Fe	Mn	Na	Zn
S1—Control	0	23.59 ^a	32.31 ^a	0.35 ^{cd}	0.20 ^c	1.06 ^c	0.80 ^{a-d}	2.86 ^{bc}	0.08 ^d	36.78 ^{abc}	5.00 ^{de}	253.00 ^{de}	38.00 ^{de}	700.00 ^{cd}	29.00 ^{de}
S1—Poultry	1	19.90 ^{abc}	29.73 ^{abc}	1.01 ^{ab}	0.58 ^{ab}	3.00 ^a	0.78 ^{bcd}	3.88 ^{abc}	0.33 ^{ab}	37.84 ^{ab}	11.00 ^{a-d}	307.67 ^{cd}	60.67 ^{bc}	1500.00 ^{ab}	49.33 ^{a-d}
	2	17.89 ^c	26.71 ^{bc}	0.82 ^{abc}	0.55 ^{ab}	3.76 ^a	0.83 ^{ab}	1.40 ^c	0.28 ^{abc}	39.89 ^a	10.00 ^{cd}	401.00 ^{bc}	65.00 ^{bc}	1500.00 ^{ab}	55.00 ^{abc}
	3	18.93 ^{bc}	26.07 ^c	1.17 ^a	0.63 ^a	3.45 ^a	0.80 ^{a-d}	3.64 ^{abc}	0.43 ^{ab}	36.91 ^{abc}	16.33 ^{ab}	406.00 ^{bc}	74.00 ^{ab}	1900.00 ^a	63.00 ^{ab}
S1—Goat	1	20.69 ^{abc}	29.73 ^{abc}	1.07 ^{ab}	0.56 ^{ab}	3.14 ^a	0.81 ^{abc}	6.73 ^a	0.34 ^{ab}	33.63 ^c	16.33 ^{ab}	460.00 ^{ab}	92.00 ^a	1800.00 ^a	58.67 ^{ab}
	2	19.83 ^{abc}	30.53 ^{abc}	1.08 ^{ab}	0.62 ^a	3.48 ^a	0.85 ^a	4.82 ^{ab}	0.32 ^{ab}	36.69 ^{abc}	10.33 ^{bcd}	544.00 ^a	73.33 ^{ab}	1800.00 ^a	50.00 ^{a-d}
	3	21.55 ^{abc}	31.13 ^{abc}	0.90 ^{ab}	0.62 ^a	2.84 ^{ab}	0.76 ^{cd}	4.51 ^{abc}	0.25 ^{bcd}	35.61 ^{bc}	11.33 ^{abc}	421.33 ^b	48.33 ^{cd}	1500.00 ^{ab}	42.67 ^{b-e}
S2—Control	0	21.54 ^{abc}	29.18 ^{abc}	0.35 ^{cd}	0.20 ^c	1.06 ^c	0.80 ^{a-d}	2.58 ^{bc}	0.08 ^d	35.61 ^{bc}	5.00 ^{de}	253.00 ^{de}	38.00 ^{de}	700.00 ^{cd}	29.00 ^{de}
S2—Poultry	1	22.03 ^{ab}	29.94 ^{abc}	1.01 ^{ab}	0.58 ^{ab}	3.00 ^a	0.78 ^{bcd}	2.66 ^{bc}	0.33 ^{ab}	28.94 ^d	11.00 ^{a-d}	307.67 ^{cd}	60.67 ^{bc}	1000.00 ^{bc}	49.33 ^{a-d}
	2	22.25 ^{ab}	28.29 ^{abc}	0.62 ^{bcd}	0.33 ^{bc}	1.55 ^{bc}	0.68 ^e	3.48 ^{abc}	0.25 ^{bcd}	33.65 ^c	7.33 ^{cd}	137.33 ^{fg}	39.00 ^{de}	800.00 ^{cd}	36.67 ^{cde}
	3	23.30 ^a	30.57 ^{abc}	0.17 ^d	0.10 ^c	0.48 ^c	0.74 ^{de}	4.51 ^{abc}	0.08 ^d	34.91 ^{bc}	0.67 ^e	48.67 ^g	12.00 ^f	400.00 ^d	22.67 ^e
S2—Goat	1	22.67 ^{ab}	29.98 ^{abc}	1.10 ^a	0.61 ^a	3.43 ^a	0.83 ^{ab}	2.59 ^{bc}	0.41 ^{ab}	33.63 ^c	11.00 ^{a-d}	245.00 ^{def}	91.00 ^a	1400.00 ^{ab}	56.00 ^{abc}
	2	22.57 ^{ab}	31.16 ^{abc}	0.33 ^d	0.21 ^c	0.97 ^c	0.74 ^{de}	4.75 ^{ab}	0.12 ^{cd}	36.69 ^{abc}	1.00 ^e	154.00 ^{efg}	23.00 ^{ef}	500.00 ^{cd}	22.00 ^e
	3	23.20 ^a	31.64 ^{ab}	1.21 ^a	0.66 ^a	3.48 ^a	0.77 ^{bcd}	4.79 ^{ab}	0.46 ^a	35.61 ^{bc}	16.67 ^a	242.67 ^{def}	62.67 ^{bc}	1500.00 ^{ab}	67.67 ^a
Significance		**	*	***	***	***	***	**	***	***	***	***	***	***	***

ADF, acid detergent fibre; NDF, neutral detergent fibre. Different superscript letter(s) (a–g) within a column indicate differences between seasons as well as manure types and concentrations within each nutrient, in Tukey's Studentized Range (HSD) ($p < 0.05$). Significance level: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

3.2.3. Fat

The greatest fat content was recorded in goat manure-treated plants (Table 3). Manure-treated plants recorded a slight increase in fat in both seasons, except for plants that were treated with 2 t ha⁻¹ of poultry manure in season one. The fat content varied between 1.40 and 6.73% in the first season and 2.58 and 4.79% in the second season (Table 4). In season one, more (6.73%) fat content was recorded in plants that received 1 t ha⁻¹ of goat manure, whereas the application of 3 t ha⁻¹ of goat manure produced the highest (4.79%) fat content in season two.

3.2.4. Phosphorus

Poultry and goat manure increased the phosphorus content in *Sesamum alatum* plants when compared with the control (Table 3). The phosphorus content of plants that were exposed to 1 t ha⁻¹ of goat manure was more than that plants that received 2 t ha⁻¹ of goat manure and 3 t ha⁻¹ of goat manure, but levels were similar with all other manure rates (Table 3). The interaction between season and manure shows that the application of poultry and goat manure at different levels increased the phosphorus content in both seasons. However, poultry manure rates ≥ 2 t ha⁻¹ and 2 t ha⁻¹ of goat manure had no effect on the phosphorus content in the second season. The highest (0.43%) P content in season one was recorded with the application of 3 t ha⁻¹ of poultry manure but 3 t ha⁻¹ of goat manure in season two (Table 4).

3.2.5. Protein

The protein amount recorded with 2 t ha⁻¹ of poultry and goat manure was the greatest, but levels were similar to the protein contents achieved with 3 t ha⁻¹ of poultry and goat manure, as well as no manure treated plants (Table 3). The smallest rates of manure application (1 t ha⁻¹) recorded the least protein content. Comparison in manure types and application rates show that poultry manure promotes better protein content in *S. alatum* than goat manure. In the first season, the highest protein content (39.89%) was recorded in plants that received 2 t ha⁻¹ of poultry manure, but levels were comparable with other treatment rates except for some rates of goat manure (1 and 3 t ha⁻¹) (Table 4). The lowest protein content (28.94%) was 1 t ha⁻¹ of poultry manure in season one.

3.3. Micro-Nutrients

Plants that were exposed to 1 and 3 t ha⁻¹ of goat manure-amended soils produced the highest copper content but was similar to plants that received 1 t ha⁻¹ of poultry manure (Table 3). The highest iron levels were obtained in both 1 and 2 t ha⁻¹ goat manure-treated plants. Manganese content was highest in 1 t ha⁻¹ goat manure-treated plants. The highest sodium content was also recorded in 1 t ha⁻¹ goat manure-treated plants. Again, the zinc content was also recorded as highest in 1 t ha⁻¹ goat manure-treated plants. Plants that had no manure applied produced the least micronutrient content.

The highest copper content was recorded in season two with 3 t ha⁻¹ of goat manure, which was comparable to 1 and 3 t ha⁻¹ of poultry and goat manure-treated plants in season one and 1 t ha⁻¹ of poultry and goat manure. Manure application rates ≤ 2 t ha⁻¹ of poultry manure and 2 t ha⁻¹ of goat manure had no effect on the copper content (Table 4). Interaction between season and manure shows that the application of manure caused an increase in iron in season one when compared with the control. The highest iron content was recorded in season one with 2 t ha⁻¹ of goat manure, but the content was similar to that in 1 t ha⁻¹ of goat manure-treated plants. In season two, manure application had no effect on the iron content.

The highest manganese content was obtained with 1 t ha⁻¹ of goat manure in both seasons (Table 4). The sodium content in season one was increased by the manure application. In season two, the increased sodium content was only obtained with 1 and 3 t ha⁻¹ of

goat manure (Table 4). The interaction between season and manure shows that high levels of poultry manure and lower rates of goat manure caused an increase in zinc content in season one, whereas a lower rate (1 t ha^{-1}) of poultry manure and goat manure ($\geq 2 \text{ t ha}^{-1}$) had no effect on the zinc content in season one. In season two, the zinc content was greatest with the application of 3 t ha^{-1} of goat manure but comparable with 1 t ha^{-1} of poultry and goat manure (Table 4).

4. Discussion

4.1. Macro-Nutrients

4.1.1. Acid and Neutral Detergent Fibres

Shoots of *Sesamum alatum* plants exposed to 2 t ha^{-1} poultry manure had lesser acid detergent fibre (ADF) and neutral detergent fibre (NDF) contents than the control (Table 3). On the contrary, insignificant differences were recorded in the fibre percentage of *S. indicum* plants that were grown under 5 t ha^{-1} poultry manure treatment when compared with the control [29]. Control plants of *S. alatum* recorded the highest fibre content (Tables 3 and 4), but *Corchorus olitorius* had a significant increase in fibre content under 1 and 2 t ha^{-1} of poultry manure [12].

4.1.2. Calcium, Magnesium, and Potassium

The general increase in Ca, Mg, and K concentration of *Sesamum alatum* under manure-treated plants compared with control plants (Table 3) was probably due to nutrient release from poultry and goat manure (Table 2). However, Ca and Mg contents decreased but K content increased in *S. indicum* plants subjected to poultry manure [29]. Calcium is an important nutrient for healthy bones, contraction and relaxation of body muscles, and coagulation [21,30]. Magnesium is an enzyme co-factor in metabolic processes, protein synthesis, and like Ca, it also prevents bleeding disorders, degenerative diseases and immunological dysfunction [31]. Potassium also promotes good myosin–actin cycling and increases iron availability in the body, while it regulates the pH balance and neurotransmission [21].

The interactions between season and different manure application rates were significantly different for the Ca, Mg and K contents when compared with the control (Table 4). A similar significant interaction was also reported in *Abelmoschus esculentus* due to the effect of poultry manure application [16]. Goat manure applied at 2.5 – 12 t ha^{-1} increased the concentration of Ca, Mg, and K in *Capsicum annum* leaves during both planting seasons [21]. Again, Ca, Mg, and K contents were better in *C. gynandra* [22] and *Amaranthus cruentus* [32] plants treated with goat manure compared with the control.

The highest Ca content recorded in 3 t ha^{-1} of poultry manure-treated plants in season one as well as 1 and 3 t ha^{-1} goat manure in season two (Table 4), which was possibly due to the high levels of calcium content recorded in poultry manure in the first season and goat manure in the second season (Table 2). Poultry manure with higher Mg content suppressed the Mg concentration in *S. alatum* edible shoots, but lower rates of application showed improvements when compared with the controls of each season. Organic manure is used in crop production for its ability to increase harvestable yields and also to replenish soil nutrients for improved plant quality [12].

4.1.3. Fat

Poultry manure-treated *S. alatum* plants had insignificant differences in fat content when compared with the control (Table 3), but *S. indicum* [29] and *Abelmoschus esculentus* [16] had a significant reduction in the fat content when poultry manure was applied. Further, 1 and 2 t ha^{-1} of poultry manure treatment resulted in an increase in the fat content of *Corchorus olitorius* [12]. Nitrogen applied at high rates limits fat availability in plants [16]. This plant growth nutrient plays a key role in plant metabolism [33]. The fat content recorded with 1 and 2 t ha^{-1} of poultry manure in the present study (Table 4) was greater than the fat content of *C. olitorius*, achieved with the same manure application rates [12].

4.1.4. Phosphorus

An increase in P content in *S. alatum* plants exposed to poultry and goat manures (Table 3) was similar to the higher *C. olitorius* P content under poultry manure [12] compared with control plants. Poultry manure application on *A. esculentus* significantly increased the fruit P concentration [16]. The increase in leaf P content was reported in *Amaranthus cruentus* [32], *Capsicum annuum* [21], and *C. gynandra* [22] when goat manure was applied. The increase in N accessibility to plants led to increased P absorption by plants [33].

4.1.5. Proteins

There were insignificant differences between manure treatment rates $\geq 2 \text{ t h}^{-1}$ and controls on *Sesamum alatum* protein content; the highest was recorded in a 2 t h^{-1} poultry manure-treated plant (Table 3). A similar study on *S. indicum* reported an insignificant difference in the protein percentage when 5 t h^{-1} of poultry manure was applied [29]. The current findings are contrary to the significant increase in protein concentration in *Corchorus olitorius* [12] and *Abelmoschus esculentus* [16] plants treated with poultry manure. The highest protein content (39.89%) recorded with 2 t h^{-1} of poultry manure in season one (Table 4) was higher than the protein content recorded with same manure in *C. olitorius* [12] and *A. esculentus* [16]. Protein is a nitrogen-dependent nutrient [16]; this is also true for phosphorus [33]. The high rainfall seen in the second season may have altered the availability of soil nutrients, which promotes protein synthesis in *S. alatum* plants grown during this season, hence the variation (Table 1).

4.2. Micro-Nutrients

Plants that received 1 and 3 t ha^{-1} of goat manure had a significant increase in Cu content when compared with the control (Table 3). On the contrary, an insignificant response was reported in the Cu content of *S. indicum* under poultry manure treatment [29]. Goat manure application to *S. alatum* plants resulted in a significant increase in Fe content, whereas rates $\geq 2 \text{ t ha}^{-1}$ of poultry manure had no significant effect when compared with the control (Table 3). The application of poultry manure at 5 t ha^{-1} caused a significant increase in the Fe content of *S. indicum* [29]. Plants that were treated with different rates of poultry and goat manure, except for 3 t ha^{-1} poultry and 2 t ha^{-1} goat manure, had a significant increase in Mn content when compared with the control (Table 3). The Mn content in *S. indicum* was increased with poultry manure application at 5 t ha^{-1} [29]. The manure application on *S. alatum* plants caused a significant increase in the sodium content. This was also true for the Zn content, except for plants that received 2 t ha^{-1} of goat manure. The Na and Zn contents were significantly increased with 1 t ha^{-1} goat manure when compared with the control (Table 3). Sodium and zinc concentrations in *S. indicum* plants grown under poultry manure soil amendments showed insignificant differences when compared with control plants [29]. Goat manure also increased the Cu, Fe, Mn, Na, and Zn content in *C. gynandra* plants [22].

5. Conclusions

Poultry and goat manure application led to increased levels of Ca, Mg, K, P, and micronutrients in *Sesamum alatum*. The increase in nutrient concentrations in *S. alatum* plants treated with manure over the control suggests that poultry and goat manures are useful in the improvement of crop nutrient content. However, ADF, fat, NDF and protein content in *S. alatum* needed no manure amendments to show its comparative potential in agronomy and nutrient concentration amongst food plants. The application of poultry and goat manure on *S. alatum* showed no significant differences in nutrient improvements except for the fat content recorded with 2 t ha^{-1} of poultry manure. Goat manure is best for the increase in nutrient content in *S. alatum*. However, poultry manure can also be used as an equal alternative in the absence of goat manure.

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