Comparative assessment of agro-morphological traits and nutrient content of *Sesamum alatum* in response to poultry and goat manures

By

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DEDICATION

This work is exceptionally dedicated to my mother (Gladys T Mbatha), my father (Funokwakhe N. H Mbatha), and all my siblings (alive and dead), for the moral upkeep, their endless devotions, inspirations, encouragement, and their doubtless belief in me even when impediments and predicaments appeared greater than my capabilities. To my social and academic friends who have been the backbone of my academic achievements. Last, but not least, to all wild food gatherers and promoters of the world who protect and feed us with environmental wisdom. This work is also loyal to the book titled "*Don't Die in the Bundu*" by Colonel D.H Grainger, O.B.E., E.D.

DECLARATIONS

The research described in this dissertation, with dually acknowledged content from other sources, is my original work carried out in the Department of Botany at the University of Zululand, KwaDlangezwa under the guidance of Dr. N.R. Ntuli and Dr. S. Mavengahama. This study has never been presented for qualification consideration in any other tertiary or research institution.

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Signature: 

We certify that the above statement is correct.

Dr. N.R. Ntuli (Supervisor – UNIZULU)

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Dr. S. Mavengahama (Co-Supervisor – NWU)

Signature: 

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PRESENTATION

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PUBLICATIONS

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ABSTRACT

Sesamum alatum Thonn. is one of the scarcely known and highly nutritious leafy vegetables that is still collected from the wild or as weeds among crops in South Africa. The plant is also used for medicinal and cosmetic purposes in Africa and elsewhere. Despite its importance and agronomic potential, 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* agro-morphological traits and nutrient content to the application of poultry and goat manures. This study was conducted under rain-fed shade cloth conditions during the summer months of 2018 and 2019. Pots (20L) were filled with 60 kg of soil mixed with poultry and goat manures at 0, 1, 2, and 3 t ha^{-1} each. The layout was a completely randomized design (CRD) of 2 × 4 factorial combinations. Taller plants with numerous branches that produced many and bigger leaves and heavier shoots were recorded in season two. The application of manure resulted in taller plants with profuse branching, many, and broader leaves as well as heavier dried shoots. However, goat manure was more effective than poultry manure. The recommended rates for optimum plant agro-morphological productivity were ≥ 2 t ha^{-1} for both manures except for the seed mass. Application rates ≥ 2 t ha^{-1} of goat manure gave the best vegetative and reproductive growth in *S. alatum*. Poultry and goat manure application led to an increase in moisture content, Ca, Mg, K, P, and micronutrients in *Sesamum alatum*. Goat manure produced the highest nutrient content of *S. alatum* than poultry manure, although differences were not substantial. Therefore, both manures could be equally used to improve agro-morphological traits and nutrient content of *S. alatum*.

Keywords: Wild leafy vegetables, *Sesamum alatum*, goat manure, poultry manure, vegetative traits, reproductive traits, nutrient content.

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List of Abbreviations

ADF	Acid Detergent Fibre
Al	Aluminium
AOAC	Association of Official Analytical Chemists
ANOVA	Analysis of Variance
ARC	Agricultural Research Council
AVRDC	Nutritional and Health supervised by the World Vegetable Centre
CEDARA	Soil Fertility and Analytical Services, KwaZulu-Natal Department of Agriculture and Rural Development, Pietermaritzburg, South Africa
Ca	Calcium
Chl	Chlorophyll
Chl–a	Chlorophyll – a
Chl–b	Chlorophyll – b
CSIR	Council of Scientific and Industrial Research
CRD	Completely Randomized Design
Cu	Copper
DAFF	Department of Agriculture, Forestry, and Fisheries
DAS	Days after sowing
DASR	Days after shoot removal
DMSO	Dimethyl Sulphoxide
DST	Department of Science and Technology
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
GLM	General Linear Model
GM	Goat manure
HSD	Honestly Significant Difference
H_2S	Hydrogen Sulfide
ICP–OES	Inductively Coupled Plasma Optical Emission Spectrometry
IV	Indigenous Vegetable
K	Potassium
KZN	KwaZulu-Natal
LA	Leaf Area
MC	Moisture Content
Mg	Magnesium

Mn	Manganese
Mo	Molybdenum
N	Nitrogen
Na	Sodium
NB	Number of Branches
NDF	Neutral Detergent Fibre
NGOs	Non-Governmental Organisations
NH_3	Ammonia
NL	Number of Leaves
NMB	Number of Main/primary Branches
NP	Number of Pods per plant
NS	Not Significant
NSB	Number of Small/Secondary Branches
NSP	Number of Seeds per Pod
P	Phosphorus
PH	Plant Height
PL	Pod Length
PM	Poultry manure
PW	Pod Width
RCBD	Randomized Complete Block Design
S	Season
SAS	Statistical Analysis System
SD	Stem diameter
SDM	Shoot Dry Mass
SFM	Shoot Fresh Mass
SMC	Shoot Moisture Content
SM	Seed Mass
$t\ ha^{-1}$	Tonnes per hectare
TLVs	Traditional Leafy Vegetable(s)
UNIZULU	University of Zululand
WHO	World Health Organization
WLVs	Wild Leafy Vegetable(s)
Zn	Zinc

Chapter One

Introduction

1. Introduction

South Africa consists of an enormous pool of cultural diversity and flora biodiversity, which includes several edible wild leafy vegetables used by many people in their everyday survival patterns for food and medicine (Odhav et al., 2007; Mavengahama, 2013). Wild leafy vegetables (WLVs) also known as traditional leafy vegetables (TLVs) are herbaceous plants whose soft and tender stems, leaves, and young shoots, as well as flowers, are eaten as a sauce or salad by many people through habits, customs, and culture (Mathaba, 2017; Ejoh et al. 2021a). These vegetables are very vital in the food security and per capita income of many financially challenged rural and semi-urban communities in South Africa and other parts of the world (Mathaba, 2017; Houdegbe et al., 2018; Ejoh et al., 2021b). Wild vegetables are inexpensive food plants for the marginal sector's economy as they are easily accessible and locally available to low-income families (Lewu and Mavengahama, 2010; Houdegbe et al., 2018). The increasing realisation of the nutritional and medicinal importance of WLVs in Africa depicts them as emerging cash crops to many low-income people, but most of them have received little attention in agronomy and food extension research (FAO, 2012).

Sesamum alatum Thonn. of the Pedaliaceae family are an annual, herbaceous nutraceutical rich leafy vegetable gathered from the wild in South Africa in KwaZulu-Natal Province (Ntuli, 2019) and India (Sarath Babu et al., 2016). It is one of the scarcely known edible WLV documented as an important food plant with exceptional nutrients and agronomic potential (Frison et al., 2006; Sarath Babu et al., 2016; Ntuli, 2019). There are reports of informal cultivation of the species in different parts of the world (Bedigian, 2018). This plant is native in warm and humid (tropical) summer regions of Africa (Akhila and Suhara-Beevy, 2013; Sarath Babu et al., 2016), introduced in the Arabian Peninsula (Akhila and Suhara-Beevy, 2013), India (Akhila and Suhara-Beevy, 2013; Sarath Babu et al., 2016) and Madagascar (Sarath Babu et al., 2016). This wild plant has potential for domestication as an economic vegetable because of its high nutrient content (Ntuli, 2019) and medicinal importance (Bedigian, 2018). *Sesamum alatum* has many different uses in Africa, India, China, and Arabian Peninsula. It is eaten as a vegetable and/or used as ayurvedic medicine by rural villagers to cure diabetes, bacterial infections (Sundarakumar and Karmegam, 2018), diuretics, (Muhammed and Shinkaf, 2014), and diarrhoea (Sarath Babu et al., 2016).

Improving crops' agronomic traits can be done by using traditional (organic) and/or synthetic (inorganic) methods. Organic manures however are thus far the best traditional way of improving soil fertility and structure for optimum and sustainable crop production (Singh, 2012). Carbon-based manures are by-product residues of animals and plants composted material (Kaburi, 2015) and they contain a wide range of essential soil components for plant growth (Anguria et al., 2017). These manures are often readily available soil fertility supplements with varying nutrient content from manure to manure (Seeiso, 2014). One of the disadvantages of organic manures is their long incubation periods (weeks to months), which facilitates the release of nutrients before they can be used by plants (Seeiso, 2014; Adediran et al., 2015). Climate change has affected soil richness negatively and organic manures have been a significant tool to enhance soil productiveness (FAO, 2012).

In a study by Alege et al. (2013) poultry manure resulted in significantly increased plant height, number of branches, number of leaves, stem girth, number of pods, number of seed per pod, 1000 seed mass, and seed yield per plant in *S. indicum*. Goat manure application also increased the plant height, stem girth, leaf length, leaf width, and leaf yield of *Corchorus olitorius* (Garjila et al., 2017), *Cleome gynandra,* and *Amaranthus hybridus* (Seeiso and Materechera, 2014).

The nutrient content of *S. indicum* leaves was increased by poultry manure application (Akande et al., 2011; Alege et al., 2013; Anguria et al., 2017), except for crude protein and Zn content at some rates (>6 t ha^{-1}) (Alege et al., 2013). Poultry manure application at rates above 6 t ha^{-1} increased seed crude protein in *S. indicum* (Anguria et al., 2017). Goat manure increased the crude protein content of *Cleome gynandra* and *Amaranthus hybridus* leaves and seeds (Seeiso and Materechera, 2014).

1.1 Problem statement

Sesamum alatum is one of the highly nutritious indigenous wild leafy vegetables. However, it still lacks agronomic recommendations and protocols for growing it in

South Africa for optimum production. Furthermore, there are no comprehensive agro-morphological and nutrient analysis studies of *S. alatum* under different organic fertilizers. Animal manures except goat manure have been applied as organic manures to *S. indicum*, a domesticated close relative of wild *S. alatum*. Animal manures are easily accessible to most rural subsistence live-stock farmers (chickens and goats) in northern KwaZulu-Natal. With knowledge on the importance and nutritional value of *S. alatum* to many rural households, it is therefore vital to cultivate and improve agro-morphological traits and nutrient content of *S. alatum* through organic farming. This information will also contribute to the domestication and large-scale farming of this leafy vegetable.

1.2 Research aim

This study aimed to examine the response of *S. alatum* agro-morphological traits and nutrient content to the application of poultry and goat manure at different rates.

1.3 Objectives

To attain the aim, the objectives of the study were:

- To determine the effect of poultry and goat manures on agro-morphological traits of *S. alatum*.
- To analyze the effect of poultry and goat manures on the nutrient content in *S. alatum* shoot tips.

1.4 Research questions

- How do the agro-morphological traits of *S. alatum* respond to the application of poultry and goat manures?
- What is the effect of poultry and goat manure application on the nutrient content of *S. alatum* shoot tips?

1.5 Research hypotheses

- **H_0**: The agro-morphological traits of *S. alatum* are not increased by the application of poultry and goat manures.
- **H_1**: Poultry and goat manure application increase agro-morphological traits of *S. alatum*.
- **H_0**: The proximate and mineral quantity of *S. alatum* shoot tips are not increased by the application of poultry and goat manures.
- **H_1**: The application of poultry and goat manures increases nutrient content in *S. alatum* shoot tips.

1.6 Structure of the dissertation

Chapter one presents the general introduction of the research, problem statement, research aim with specific objectives, questions, hypotheses as well as the structure of the dissertation. **Chapter two** reviews the literature on the taxonomy, origin, and geo-distribution; uses, and cultivation status of *S. alatum*. The chapter also discusses the effect of organic manures on the agro-morphological, and nutrient content of *Sesamum* species and other TLVs. Chapters three and four each contain an introduction, materials and methods, results, discussion, and conclusion. **Chapter three** presents the effect of poultry and goat manures on agro-morphological attributes of *S. alatum*. **Chapter four** focuses on the effect of poultry and goat manure application on the nutrient content of *S. alatum*. **Chapter five** gives the general conclusions with recommendations from the entire study.

Chapter Two

Literature Review

Parts of this chapter are submitted for publication as follows: Mbatha, K. C., Mavengahama, S and Ntuli, N. R. (2021). Potential of domesticating the underutilised multipurpose wild leafy vegetable, *Sesamum alatum*, under low input organic cropping systems. *South African Journal of Botany*. (**Under review**)

2. Literature review

This review outlines taxonomy, origin, geo-distribution, growth environments, cultivation, and uses of *S. alatum*. It also reviews the importance and agronomic practices of traditional leafy vegetables in rural and semi-urban areas, worldwide. It further describes the effect of poultry and goat manures on agro-morphological traits and the nutritional status of *Sesamum* species and other traditional leafy vegetables.

2.1 Taxonomy, origin, and geo-distribution of *S. alatum*

Sesamum alatum Thonn. is a member of approximately 35 species of the genus *Sesamum* L. under the family Pedaliaceae (Sarath Babu et al., 2016; Bedigian, 2015). *Sesamum alatum* is a 0.5–1.5 m tall, erect, annual, herbaceous plant with purplish-green, moderately branched glabrous stem (Masrahi et al., 2012; Sarath Babu et al., 2016). Leaves are opposite with three different leaf types: simple leaves at the bottom; trifoliate and palmate in the middle (Figure 1b and c); as well as simple leaves toward the apex (Figure 1a). These leaves have no stipules; central leaves are the biggest with a maximum leaf size (area) of 8 cm × 2 cm, margins are often undulate or entire. The petiole ranges from 1–7.5 cm long (Badigian, 2015; Sarath Babu et al., 2016).

It has bisexual, zygomorphic pink to light purple flowers with pink spots in their corolla; and grows solitarily on short pedicels in the axil of each leaf (Figure 1a) (Akhila and Suhara-Beevy, 2013; Sarath Babu et al., 2016). Fruits are oblong narrow loculicidal capsules of 5 cm × 0.7 cm in size with four carpels and longitudinal packed dehiscing seeds. Seeds are rough, with wings at either end or change from white (immature seeds) to dark brown (mature seeds) in colour. Their seed size (excluding wings) ranges between 2–3 mm long (Sarath Babu et al., 2016). The morphology of *S. alatum* seed can be categorized as rhododendron endospermic type because of the 2 – 3 cm long wings at both ends (Hartmann et al., 2002). Morphological features used to distinguish *S. alatum* from its close relative *S. indicum* are winged seeds and palmate leaves in *S. alatum* (Bedigian, 2015; Sarath Babu et al., 2016).

Africa is the main centre of origin for the *Sesamum* genus and India is the secondary because of a large pool of *Sesamum* species in these continents (Akhila and Suhara-

Beevy, 2013; Bedigian, 2018). *Sesamum alatum* is widely distributed in tropical and subtropical regions of Africa, Asia, Europe, the Mediterranean, Central, and South America (Akhila and Beevy, 2013; Bedigian, 2015). In Africa and Asia, it predominantly grows in sandy soils that are found along roadsides, around many villages, gardens (Masrahi et al., 2012; Sundarakumar and Karmegam, 2018), beach sides (Akhila and Suhara-Beevy, 2013), and landfill sites (Ousmane et al., 2017).

Figure 2. 1. *Sesamum alatum* mature plant with flowers and fruits/pods (arrows) as well as apex simple leaves (a); juvenile plant with simple lobed and palmate leaves (b) and immature plant with trifoliate and palmate leaves (c). (Photo: Google photos (a) and Khulekani C Mbatha (b and c))

2.2 Uses and nutritional value of *S. alatum*

Sesamum alatum is eaten as a wild leafy vegetable (WLV) ("*imifino*" in northern KwaZulu-Natal, South Africa (Ntuli and Zobolo, 2016), and India (Mariod et al., 2017). It is counted among emergency foods eaten during famine and malnutrition in some parts of the world (Bedigian, 2018). In Africa and Asia, tender leaves, young shoots, young pods, and seeds are cooked and eaten fresh and dried in soups, sauces, and cakes (Sarath Babu et al., 2016; Mariod et al., 2017; Bedigian, 2018). Young pods are eaten and/or used for oil production in Sudan (Mariod et al., 2017). Seeds can be eaten as a snack (Welcome and Van Wyk, 2019) or cooked separately as a relish or with other rural and semi-urban WLVs such as cucurbit leaves and fruits to be served with staple dishes (Sarath Babu et al., 2016; Mariod et al., 2017) or used as sauce condiments (Frison et al., 2006).

The leaves, roots, and seeds of *S. alatum* are high in antioxidants, thus making it health valuable (Akhila and Suhara Beevy, 2013; Mariod et al., 2017). In India, leaves and seeds are used to treat diabetes, renal and bacterial infections (Rajkiran et al., 2011; Sundarakumar and Karmegam, 2018); diarrhoea, intestinal disorders, and its seed oils act as an aphrodisiac (Sarath Babu et al., 2016; Mariod et al., 2017). Roots, stems, and leaves are used in Nigeria to treat diuretics and stomach problems (Muhammed and Shinkaf, 2014). Fresh leaves and seeds are valued for their oils and the mucilaginous substance that has hair shampoo properties, cloth washers, and hair conditioner (Bedigian, 2018). The plant is also very essential in veterinary science and medicine, leaves decoction is used for fertility promotion in cows and increases antioxidant activities and vitamin C in rats (Mariod et al., 2017).

In Mali, the entire plant is tied around the waist of a teething infant to protect them from evil spirits (Bedigian, 2018). Northern Nigerians inhale the smoke of the plant for sorcery protection, and they drink the root powder mixed with sour milk to prevent Rana (diarrhoea plus fever) disease symptoms. The whole plant alone or in combination with other similar spiritual plants are used to cause quarrelling of a group of people by placing it anywhere in the homestead (Bedigian, 2018). *Sesamum alatum* contains essential macro and micro-nutrients. Previous studies conducted in South Darfur, Sudan (Ali et al., 2016) and KwaZulu-Natal province in South Africa (Ntuli, 2019) on WLVs recorded very high nutrient content for every 100 g edible portion of *S. alatum* leaves (Table 2.1).

Table 2. 1 Proximate and mineral content of *S. alatum*

Nutrients	**Proteins**	**Fats**	**Carbo-hydrates**	**Ash**	**Dry Mass**	**Moisture**	**Reference**
Amount (g/100 g (%))	31.57	1.34	41.79	17.19	91.89	8.11	Ntuli, 2019
	15.2				86.4		Ali et al., 2016
Macronutrients	**N**	**P**	**K**	**Ca**	**Mg**		
Amount ((%) 100 g^{-1})	5.58	0.5	4.25	1.88	0.5		Ntuli, 2019
				0.88	0.25		Frison et al., 2006
Micronutrients	**Mn**	**Zn**	**Fe**	**Al**	**Na**	**Cu**	
Amount (mg 100 g^{-1})	65.0	29.0	453.0	406.0	1159.4	5.1	Ntuli, 2019
		5.18	3.67			1.63	Frison et al., 2006

2.3 Ecological environments for *Sesamum* species growth

Sesamum L. species mostly grow in sandy soils (Loots, 2001), which are often low in fertility and slightly acidic (pH 5) to alkaline (pH 8) (Ogbonna and Umar-Shaba, 2011; Nurhayati et al., 2016). *Sesamum alatum* often grows in dry and/or highly drained soils, but seed germination and germination rates are dependent on abundant rainfall (Bediginia, 2004). Annual rainfall ranging from 500–1000 mm is suitable for the optimal growth of *Sesamum* species (Ogbonna and Umar-Shaba, 2011; Loots, 2001). Successive to high rainfalls, must be a sunny climatic condition of 18 to 30 °C (Ogbonna and Umar-Shaba, 2011; Nurhayati et al., 2016). These high temperatures are not only a requirement for seed germination but also help with excess water evaporation as *Sesamum indicum* seedlings cannot withstand excess water (Ogbonna and Umar-Shaba, 2011).

2.4 Cultivation status of *S. alatum* and other *Sesamum* species

Sesamum alatum and other wild *Sesamum* species are cultivated as landraces in the savanna regions of African countries such as Benin, Ethiopia, Ivory Coast, Sudan, Senegal, Mali, Niger, Namibia, and Zambia (Bedigian, 2004 and Bedigian, 2018). Some *Sesamum* species cultivated at the household level in Nigeria include *S. alatum, S. indicum,* and *S. radiatum* (Alege et al., 2011). Among these, *S. indicum* is the only commercialized and predominantly used *Sesamum* species (Alege et al., 2011; Anguria et al., 2017; Bedigian, 2018). The cultivation and importance of *S. radiatum* are highly reported in Benin at the household level (Adéoti et al., 2012). Most of these countries intercrop wild *Sesamum* species with the main crops (Akande et al., 2011). However, *S. alatum* is still collected from the wild in India (Sarath Babu et al., 2016) and South Africa (Ntuli, 2019).

2.5 Importance and organic agronomic practices of wild leafy vegetables

Wild leafy vegetables are defined as tender stems, leaves, roots, flowers, pods, and seeds of plants that are palatable raw, cooked, steamed, baked, dry, and pounded for sauce supplements (Ntuli et al., 2012; Mathaba, 2017). Wild leafy vegetables are called by many names in literature such as African Indigenous Vegetables, African

Leafy Vegetables, African Traditional Vegetables, Traditional African Vegetables, and Traditional Leafy Vegetables (Towns and Shackleton, 2019). These vegetables have been used for 200 centuries in South Africa from the Khoi and the San people (Khoisan) to the current Bantu-speaking tribes (Jansen van Rensburg et al., 2007; Ntuli et al., 2012; Sonwunmi, 2015; De Vynck et al., 2016). They are called by many ethnic names in South Africa such as *imifino* (Zulu and Xhosa), *morogo* (Sotho), and *miroho* (Venda) (Towns and Shackleton, 2019).

Wild leafy vegetables play an indisputable role in crop production, food security, food plant diversity, and creating an economy of many African families (Opiyo et al., 2015; Houdegbe et al. 2018). In Ladysmith, South Africa they provide food security to many people with annual gross earnings of approximately R700 and cannot afford commercial vegetables (Sithole et al., 2011). These WLVs are also sold in many African traditional markets mostly as medicinal plants rather than food plants (Bvenura and Afolayan, 2015; Asase and Kumordzie, 2019). In Ghana, the most selling of WLVs in local markets depends on customers' preferences, where *Xanthosoma sagittifolium*, *C. olitorius,* and *A. cruentus* are frequently sold in Kaneshie, Madina, and Agbobloshie as well as Malata markets, respectively (Asase and Kumordzie, 2019). The market sizes of WVLs are substantial in sub-Saharan Africa (Afari-Sefa et al., 2015).

Wild leafy vegetables are used by many rural people in South Africa (Mavengahama et al., 2016) and Kenya (Opiyo et al., 2015) as relish that accompanies *uPhuthu* (cooked maize meal). In Africa and elsewhere, WLVs are regarded as emerging cash crops because of their nutritional and medicinal importance (FAO, 2012). The consumption of WLVs such as *Amaranthus sp.* is not only limited to low-income families but they are also favoured to reach the commercial market (Shackleton et al., 2010). However, the perception of "poor people's crops" causes a decline in the consumption of traditional and indigenous crops as well as a shift in agronomic research towards prioritization of wild leafy vegetables in Africa (FAO, 2012; Houdegbe et al. 2018).

Most recently, in South Africa, relevant research institutions and councils such as the National Department of Agriculture, Forestry and Fisheries (DAFF), the Department of Science and Technology (DST), Agricultural Research Council (ARC), and Council of

Scientific and Industrial Research (CSIR) have started to acknowledge the role played by WLVs in the fight against food insecurity and unemployment (Bvenura and Afolayan, 2015; Shackleton et al., 2010). In Malawi, Rwanda, Tanzania, and Uganda initiatives such as the Promotion of Neglected Indigenous Vegetable Crops (IV) for Nutritional and Health supervised by the World Vegetable Centre (AVRDC) has worked successfully with these countries' NGOs in promoting Indigenous Vegetables in Eastern and Southern Africa (ProNIVA) (Achigan-Dako et al., 2014). Neglected WLVs contribute a large portion (up to 160 g per person per day) of the daily food intake of some people (Sithole et al., 2011), from the recommended 400 g daily intake of fruits and vegetables. They add excellent amounts of carbohydrates, fibres, proteins, vitamins (A, C, and E), and trace minerals, iron, zinc, and folic acid (Houdegbe et al. 2018). Moreover, WLVs particularly the dark green leafy ones comprise nitrates, oxalates, phytates, saponins, and tannins (Seeiso, 2014).

The list of domesticated WLVs still includes a few such as *Amaranthus spp*. (*A. cruentus*, *A. deflexus*, *A. greacizans*, *A. viridus, A. hybridus*), *Corchorus olitorius* and *Cleome gynandra*. These WLVs have been subjected to organic and inorganic fertilizer applications to improve their agronomic production and nutrient content (Vorster, 2007; Vorster et al., 2007; Jansen van Rensburg et al., 2012; Mavengahama, 2013; Mavengahama et al., 2015; Opiyo et al., 2015; Mavengahama et al., 2016). Many other WLVs are regarded to have received little attention by agronomic and extension research experts (Jansen van Rensburg et al., 2012; Opiyo et al., 2015; Aworh, 2018; Ntuli, 2019) and nutritionists and agricultural policymakers alike (Mavengahama et al., 2015). The improvement and domestication of WLVs will motivate the presence and use of indigenous knowledge (Wemali, 2014) while enhancing the gene pool and productivity of these plants.

Growth limiting factors to produce WLVs are no different from those of commercial crops. These factors include water, light, soil fertility, temperature, and frost (Jansen van Rensburg et al., 2012). However, WLVs' environmental adaptations are more complex and abnormal compared to most commercialised exotic crops. They tolerate water deficiency and heat (Sithole et al., 2011), wet environments (Opiyo et al., 2015) as well as other wide abiotic and biotic ecological variations (Mavengahama, 2013). The growth and production of WLVs generally require very little resource input (hormones, fertilizers, and pesticides) compared to exotic crops (Jansen van Rensburg et al., 2012). They also require very low concentrations of manure (Mofunanya et al., 2014).

2.6 Organic manure

Organic manures are organic residues of animal and plant by-products (Hoover et al., 2019; Drozdz et al., 2020). There are different types of organic manures that including green manures, composts, and farmyard manures (Kaburi, 2015). These organic residues are usually brown or black. Their dark colour helps with heat absorption and temperature regulation (Kaburi, 2015; Eifediyi et al., 2018). Organic manures comprise of the three basic plant growth elements N, K, and P plus other extra essential elements such as Na, Ca, Mg, Sulphur (S), Fe, Mn, Zn, Cu, and Mo (Das et al., 2012; Ikeh et al., 2012; Singh, 2012). The organic matter from these manures is a very important component of the topsoil strata called humus.

Poor soil fertility and arability are a problem in many places due to weather fluctuations and human activities, but organic manure has been a significant tool in the rehabilitation of these soil for enhanced structure (FAO, 2012). Nutrients provided by manures improve soil physical, chemical, and biological characteristics of the humus (Tiamiyu e al., 2012; Tovohoudji et al., 2015; Anguria et al., 2017). Humus chemical structure has necessary macro-and micro-nutrients for optimum improvement of agro-morphological traits (Das et al., 2012; Kaburi, 2015). Enhanced soil physical properties increase soil permeability, which allows easy soil drainage, aeration, and root dissemination; water holding capacity; soil structure, and soil stability (Cho et al., 2017; Anguria et al., 2017; Eifediyi et al., 2018).

Organic manure sometimes has high N content making it both an advantage and disadvantage to plants (Liu et al., 2014). Nitrogen is one of the key plant growth nutrients essential for plant greenness, proteins, amino acids, and nucleic acid, which are fundamental in plant growth and development (Muñoz-Huerta et al., 2013). However, it must be supplied at sufficient dosages to avoid both plants and environmental disturbances (Ranadheera et al., 2017). High levels of nitrogen thwart plants' optimum production and cause water pollution through run-off and/or leaching of excess nitrates (Muñoz-Huerta et al., 2013; Liu et a., 2014). Furthermore, plants absorb some of the excess nitrates making them inedible for human beings (Liu et al., 2014). Therefore, organic manures require long composting and incubation periods for nutrient conversion to necessary plant assimilates (Seeiso, 2014; Adediran et al., 2015).

The nutrient content in these organic manures varies from place to place and time to time (have spatial and temporal variations) for every country (Adediran et al., 2015; Cho et al., 2017). These nutrients come in different concentrations and dissimilarities because of different storage methods, regions, and fodder nutrient diversity consumed by these different animals (Oenema et al., 2007; Cho et al., 2017). Unlike inorganic fertilizers, organic manures are used in bulk making them labour-intensive and labour has expenses, despite their cheapness and availability of the manure itself to rural farmers (Ranadheera et al., 2017).

Sandy soils are very low in organic matter and nutrients (Anguria et al., 2017). Amending such soils with organic amendments is recommended, especially in tropical regions whose soils are reported to suffer from acidity (Sanni and Okeowo, 2016). Adding adequate organic manure into sandy soils replenishes the low and easily leaching growth nutrients and organic matter for optimum plant production (Azeez et al., 2010; Drozdz et al., 2020). Applying goat and poultry manure on the soil increases soil pH, organic matter, and nutrient content (total N and P) and exchangeable cations (K, Ca, and Mg) as well as cation exchangeable capacity (Ikeh et al., 2012; Cho et al., 2017). However, adding too much manure could result in excess nitrate and phosphorus leaching or runoff into groundwaters and adjacent water bodies causing eutrophication that threatens both environmental and human health (Ranadheera et al., 2017).

2.7 Poultry and goat manures

Poultry manure is malodourous due to the high levels of volatile organic compounds, which include aldehydes, alcohols, amines, ammonia, esters, mercaptans, hydrogen sulfide, and volatile fatty acids (Kalus et al., 2017; Ranadheera et al., 2017). These volatile compounds include ammonia (NH_3), which is the main source of this odour

(Kalus et al., 2017; Ranadheera et al., 2017). Other factors responsible for the odour in chicken manure include hydrogen sulfide, greenhouse gases, and particulate matter (Kalus et al., 2017).

Poultry manure is regarded as the most used and best domestic animal manure (Nurhayati et al., 2016; Ranadheera et al., 2017; Okorogbona et al., 2018). This manure comprises mainly carbon-based matter, which has undigested protein, carbohydrates, fibre, and commensal microbial biomass (Ranadheera et al., 2017). Poultry manure is the best source of N, which is a requirement for vigorous green growth, as well as other essential plant growth nutrients (Ranadheera et al., 2017). It is described as very stable manure at all rates with a recommendation for use in the savannah regions of Southeast Nigeria (Ogbonna and Umar-Shaba, 2012). Poultry manure contains (3.00–3.83%) N, (1.76–1.93%) P, (2.30–2.54%) K, and other macronutrients such as Ca and Mg (Haruna and Abimiku, 2012). The application of poultry manure promotes the synthesis of photo-assimilates (important for vigorous growth) in the soil, which increased the meristematic and physiological activities of the plant (Asfaw, 2020).

Goat manure is a dry odourless organic matter derived from composted goat faeces, sometimes mixed with urine. The odourless characteristic makes it have less attraction to insects such as maggots and flies (Ranadheera et al., 2017; Cho et al., 2017). Goat manure contains (1.20–1.23%) N, (0.82–0.93%) P, (0.30–0.32%) K, and other essential plant growth nutrients (Abdulmaliq et al., 2017). Potassium levels of goat manure are increased when the solid matter of goat by-product mixes with goat urine (Okorogbona et al., 2018).

Goat manure is cooler due to the low levels of N in a form of NH_3, with a stable pH and salts, but this is not always the case (Ranadheera et al., 2017). Poultry manure has higher moisture content than goat manure (Nurhayati et al., 2016; Okorogbona et al., 2018). Basic macronutrients (N, P, and K) and other micronutrients (Cu, Fe, and Mn to count a few) are either more in goat than poultry manure (Nurhayati et al., 2016) or are more in poultry than goat manure (Abdulmaliq et al., 2017; Okorogbona et al., 2018).

2.8 Effect of poultry and goat manures on growth and yield of *Sesamum* species and other traditional leafy vegetables

The application of poultry manure at 0–10 t ha^{-1} resulted in increased plant height (115.6–163.5 cm), stem girth (7.67–13.91 mm), number of branches (3.61 to 11.00 branches per plant), and the number of leaves (10.00–19.25 leaves) of *S. indicum* (Ogbonna and Umar-Shaba, 2012; Alege et al., 2013). Poultry concentrations that are below 10 t ha^{-1} decreases the leaf dry weights of *S. indicum* (Alege et al., 2013), whereas higher concentrations of 10–15 t ha^{-1} (Haruna, 2011) and 30 t ha^{-1} poultry manure (Nurhayati et al., 2016) produce the highest leaf dry weights. Yield attributes such as the number of flowers and capsules per plant, capsule length, the number of seeds per capsule, the number of seed per plant, and 1000 seed weight of *S. indicum* increased with poultry manure application rates of 2.5 to 10 t ha^{-1} (Ogbonna and Umar-Shaba, 2011; Haruna and Abimiku, 2012; Ogbonna and Umar-Shaba, 2012).

The plant height, the number of leaves, leaf size, the number of branches, and plant fresh and dry shoot masses of *Amaranthus cruentus* was increased by the application of poultry manure (Law-Ogbomo and Ajayi, 2009; Adewole and Dedeke et al., 2012; Oyedeji et al., 2014; Mofunanya et al., 2014). Poultry and goat manure applied to *Amaranthus hybridus* caused in a significant increase in plant height, stem thickness, leaf quantity, and leaf size (Ekwealor et al., 2020). *Amaranthus cruentus* leaf area index was also increased by poultry manure application from 5 and 10 t ha^{-1} (Law-Ogbomo and Ajayi, 2009). For black and white seed varieties of *S. indicum* 30 t ha^{-1} of poultry manure was the best-recommended application rate for early flowering (Nurhayati et al., 2016). Poultry and goat manure delayed the flowering days of *Corchorus Olitorius* L. (Ayeni and Oye, 2017). The application of poultry manure at 5.8 and 13.4 t ha^{-1} increased the shoot dry matter yield of *A. cruentus* (Maerere et al., 2001).

The application of goat manure at 3 t ha^{-1} (Law-Ogbomo and Osaigbovo, 2016) and 15 t ha^{-1} (Garjila et al., 2017) improved the plant height, the number of leaves per plant, leaf area, and leaf yield per hectare. The stem girth (Garjila et al., 2017), the number of leaves per plant, and the number of branches per plant (Law-Ogbomo and

Osaigbovo, 2016; Ayeni and Oye, 2017) of *Corchorus olitorius* were also increased by the application of goat manure. Six to eighteen tonnes per hectare of goat manure improved the plant height, the number of leaves per plant, leaf area, and leaf fresh yield per plant of *A. cruentus* (Abdulmaliq et al., 2017). The shoot dry matter yield of *A. cruentus* (Maerere et al., 2001) and *C. olitorius* (Law-Ogbomo and Osaigbovo, 2016) increased with goat manure application at 5.8 and 13.4 t ha^{-1}. Both fresh and dry mass of *Cleome gynandra* and *A. hybridus* shoots increased with the application of goat manure at 0.5 t ha^{-1} (Seeiso and Materechera, 2014). Reproductive traits such as flowering time and quantity of flowers increased with the application of goat manure at 30, 45, and 60 t ha^{-1} for both black and white seed varieties of *S. indicum* (Nurhayati et al., 2016). No studies to date have recorded any agronomic practices for improving morpho-agronomic traits of *S. alatum* under any manure application.

2.9 Effect of poultry and goat manures on the nutrient content of *Sesamum* species and other traditional leafy vegetables

The application of poultry manure at 5 t ha^{-1} increased the moisture content, carbohydrates, fibre, K, Na, and Zn content however, this rate suppressed some nutrients such as proteins, fats, ash, and mineral elements such as Ca, Cu, Fe, Mg and Mn in *S. indicum* leaves (Alege et al., 2013). In contrast, 2.5 to 6 t ha^{-1} caused an increase in proteins, ash, fats, N, P (Anguria et al., 2017), Ca, and Mg of *S. indicum* leaves (Akande et al., 2011). Poultry manure application at 5 and 10 t ha^{-1} increased the ash, fat, and protein content of *Amaranthus caudatus* and *Amaranthus cruentus* (Kahu, 2017). There was a significant increase in the nutrient content of *A. cruentus*, *A*. *hydridus*, *A. deflexus,* and *A. spinosus* at 0.03 and 0.55 t ha^{-1} poultry manure application, respectively (Oyedeji et al., 2014; Mofunanya et al., 2014). However, a high poultry manure rate of 10 t ha^{-1} increased the proximate content in *A. caudatus* compared to lower manure rates, but differences are insignificant for *A. cruentus*. Furthermore, high poultry manure rates (10 t ha^{-1}) are advantageous to shelf-life as they produced plants with low moisture content than 5 t ha^{-1} application (Kahu, 2017).

Application of goat manure at 0.5 t ha^{-1} rate increased the protein content of *C. gynandra* and *A. hybridus* from (5.8 to 14.2%) and (6.7 to 13.44%), respectively (Seeiso and Materechera, 2014). Eight tons per hectare of goat manure increased the

P content of *C. gynandra* exceptionally compared to the increase of other mineral contents such as Ca, Cu, Fe, K, Mg, Mn, Na, and Zn (Sowunmi, 2015). The nutrient content of *S. alatum* was only recorded from the plants that are growing in the wild (Ntuli, 2019), but not the cultivated plants. Therefore, the record on the effect of manure application on the nutrient content of these plants is essential for its recommendation for domestication and large-scale farming.

2.10 Conclusion

This chapter discussed the taxonomy, origins, geo-distribution, and uses of *S. alatum*. It also outlined the ecological environments for the growth and cultivation of *S. alatum*. The review further reflected on the importance of wild leafy vegetables and gave a brief definition of organic manures and an in-depth understanding of poultry and goat manure as well as their effect on Sesamum species and other traditional vegetables. This knowledge shows that WLVs play a significant role in food insecurity and scarcity during a famine. *S. alatum* fell amongst the highly nutritious WLV comparable with *Amaranthus hydridus*. The uses and levels of nutrients found in *S. alatum* have a high domestic and commercial potential if given necessary agronomic interventions. However, to achieve this optimum manure application rates for different seasons and environmental conditions must be recommended, hence the rationale to conduct these experiments. The following chapter three is based on the effect of poultry and goat manure on *S. alatum* vegetative traits and yield.

Chapter Three

Effect of poultry and goat manures on agro-morphological traits of *S. alatum*

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3.1 Introduction

Sesamum alatum belongs to the Pedaliaceae family and is one of the most important oilseed genus *Sesamum* L. (Sarath Babu et al., 2016). Native to Africa and introduced elsewhere, *S. alatum* often grows in tropical and subtropical sandy regions of Africa, Asia, Europe, Mediterranean, Central, and South America along roadsides, gardens, and seashores (Sundarakumar and Karmegam, 2018). It is a green mucilaginous herb planted as a landrace in Benin, Ethiopia, Ivory Coast, Sudan, Senegal, Mali, Niger, Namibia, and Zambia (Bedigian, 2004), and gathered as a wild leafy vegetable in South Africa (Ntuli, 2019) and India (Sarath Babu et al., 2016).

Rural communities in Africa and India use *S. alatum* for its purported high nutrient content, vitamins, and medicinal properties. *Sesamum alatum* is a hardly known wild leafy vegetable (WLV) of great importance in KwaZulu-Natal, South Africa (Ntuli et al., 2019) and other places of the world (Bedigian, 2004 and 2018). It is personally used or sold as a wild leafy vegetable (WLV) and ayurvedic medicine (Sarath Babu et al., 2016). Tender leaves, shoot tips, tender pods, and pounded seeds of *S. alatum* are cooked independently as a relish and/or along with other WLVs (Rajkiran et al., 2011; Sarath Babu et al., 2016). This is done to complement the diet of rural dwellers, which is mostly starch-dominated (Mavengahama, 2013). The mucilaginous substance in the leaves and seeds of *S. alatum* is used as an aphrodisiac and hair shampoo in Africa and India (Bediginia, 2004).

Despite these vegetables having wide environmental tolerance, the cultivation of WLVs has not been prioritized in South African agronomic research. In Nigeria, *S. alatum* is cultivated at the household level with no agronomic or horticultural records on recommended cropping systems (Alege et al., 2011). Soil fertility is an important factor in the production of good yields and increases income; food, and nutrient security. However, maintaining adequate soil fertility is not easy for resource-poor farmers, especially those on sandy soils with low organic matter. This is due to the high costs of the chemical manures usually recommended for good crop production and the high permeability of sandy soils, which does not favour sufficient nutrient retention. Hence, organic manures are a better alternative for rural farmers' crop production under these conditions. These manures provide macro and micronutrients essential for plant growth and enhanced soil fertility (Hoover et al., 2019; Drozdz et al., 2020), as well as organic matter for improved soil structure; microbial and physicochemical properties, and overall agronomic productivity and sustainability (Aynla et al., 2018). They also increase soil permeability in compacted soils; increase water holding capacity and stability for erosion and soil degradation (Haruna, 2011 b; Anguria et al., 2017; Cho et al., 2017; Eifediyi et al., 2018) while providing plants with sufficient nutrients. Poultry and goat manures have been reported to not only support good crop production but also improve environmental conditions (Eifediyi et al., 2018 Hoover et al., 2019).

The application of poultry manure resulted in increased plant height, stem girth, number of branches, and the number of leaves of *S. indicum* (Ogbonna and Umar-Shaba, 2012; Alege et al., 2013). Poultry manure applications greater than 10 t ha^{-1} produced the highest leaf dry mass of *S. indicum* (Haruna, 2011; Nurhayati et al., 2016). The number of days to flower formation decreased significantly with the application of 5 to 10 t ha^{-1} poultry manure (Ogbonna and Umar-Shaba, 2011). However, the number of pods per plant, pod length, the number of seeds per pod, the number of seeds per plant, and 1000 seed mass of *S. indicum* increased with poultry manure application rates 5 and 10 t ha^{-1} (Ogbonna and Umar-Shaba, 2012). Contrary to increased poultry manure rates of greater than 2.5 t ha^{-1} decreased the number of pods per plant, the number of seeds per plant, and 1000 seed mass (Haruna and Abimiku, 2012). Goat manure application at 3 and 15 t ha^{-1} improved the plant height, the number of leaves per plant, leaf area and leaf yield per hectare, and stem girth (Garjila et al., 2017), number of leaves and branches per plant of *Corchorus olitorius*. (Law-Ogbomo and Osaigbovo, 2016; Ayeni and Oye, 2017)

Sesamum alatum is recorded amongst scarcely known and underutilized highly nutritious wild leafy vegetables in South Africa (Ntuli, 2019). Despite its food (nutritional), medicinal, and cosmetic importance in Africa, India, Madagascar, and Australia (Sarath Babu et al., 2016), *S. alatum* is still an underutilised and less-researched wild leafy vegetable. There is no literature on the agronomic protocols for improving *S. alatum* growth and yield using organic manures. The objective of the current study was to examine the response of *S. alatum* agro-morphological traits grown under the application of poultry and goat manure.

3.2 Materials and Methods

3.2.1 Study area, seeds, manure, and soil sources

This agronomic study was conducted at the University of Zululand Botany Research Nursery, KwaDlangezwa campus (28° 85’ 24’’ S, 31° 84’ 91’’ E) in KwaZulu-Natal province, South Africa. The experiments were done during the spring to summer months (September–December) of 2018 and 2019 under a (40%) sunlight blocking polycarbonate net roofed shelter (600 µmol/m^2/s light intensity), with exposed sides. Seeds were collected from Mseleni (27° 36′ 71″ S, 32° 53′ 93″ E), a rural village in the northern KwaZulu-Natal, under Umhlabuyalingana Local Municipality. The seed collection site is described botanically as a Sandy Bushveld under the Maputaland - Pondoland - Albany hotspot (Mbatha, 2017). Poultry and goat manures were obtained from the University Agriculture Dairy Farm. The sand was collected from the Mangezi river near the university and the loam soil was collected from an agricultural crop garden near the shelter.

3.2.2 Soil-manure mixing and experimental design

A sand-loam soil mixture was used as a medium in these experiments. Each pot was filled with 60 kg of soil. The soil was mixed in a ratio of (70%) river sand and (30%) humus-rich loam soil plus manure at specific doses. Manure and soil for each specific rate were mixed in an open space before filling up five pots per concentration. Pot trials were carried out for two summer seasons (from September to December 2018 and 2019). Poultry and goat manures were applied at the following rates, 0; 1; 2, and 3 t ha^{-1} (Table 3.1). Manure in tons per hectare of application rates was converted to grams per 20 kilograms of soil, which was equivalent 2 000 000 kilograms of soil per hectare for a furrow slice. After soil–manure mixing all pots were irrigated adequately and covered with black plastic for a 10–day incubation period. The incubation process facilitates mineralisation and cation exchange in the soil and manure mixture for fertility uniformity. Whereas the plastic covering enhances the soil temperature or heat levels and maintains adequate moisture. After covering, pots were then arranged in a Completely Randomized Design (CRD) of 2 × 4 factorial combinations (Table 3.2 and Figure 3.2). Sowing was done immediately after the 10-day incubation period (Seeiso and Materechera, 2014). Seeds (100) were broadcasted in each pot and covered with a layer (1–2 mm) of sprinkled sand. After the broadcast, pots were irrigated with (5 L each) water.

Table 3. 1 Manure rates conversions from tons per hectare to grams per 20 kilograms for soil (Kiran et al., 2016).

Manure rates (t ha^{-1})	**Manure amount (g) to 20 kg of soil**
0	0
1	10
2	20
3	30

One hectare of land (20 kg of soil per pot) = 2 000 000 kilograms of soil in a furrow slice.

Table 3. 2. Sketch of pots setup in a completely randomized design.

0 C	**3 P**	**2 P**	**2 G**	**1 G**
2 G	**1 P**	**3 G**	**0 C**	**3 P**
1 G	**3 P**	**1 G**	**2 P**	**3 G**
3 G	**1 P**	**0 C**	**3 P**	**1 P**
1 G	**0 C**	**2 G**	**3 G**	**2 P**
3 P	**2 G**	**2 P**	**1 P**	**2 P**
1 G	**3 G**	**1 P**	**2 G**	**0 C**

C, control; P, poultry; G, goat in tonnes per hectare (t ha^{-1}).

Figure 3.1. Pots filled with the soil-manure mixture and covered with black plastics for incubation. (Photo: Khulekani C Mbatha)

Figure 3. 2. Completely randomized design of pots. (Photo: Khulekani C Mbatha)

3.2.3 Soil sampling, preparation, and fertility examination

River sand, loam (collected at 30–60 cm soil depth), sand-loam mixture, and manures were air-dried for seven days and then sieved through a 2 mm sieve to eliminate stones and debris. Thereafter, they were sent to CEDARA (Department of Agriculture and Rural Development, KwaZulu-Natal section) for physicochemical analysis. To examine soil nutrients and other components present such as soil pH, organic carbon, organic matter, acidity, moisture, total N, phosphorus, and exchangeable cations (Ca, Cu, Mg, Mn, Na, K, and Zn) as well as soil components (clay, silt, and sand) proportions.

3.2.4 Soil physicochemical analysis

The nutrient and element composition of the soil was analysed using the method by Manson and Roberts (2000). Soil samples were spread out in drying trays air-dried at room temperature. When dry, the samples were crushed between rubber belts on a soil crusher and passed through a 1–mm sieve. The remaining uncrushable coarse material that is more than 1 mm such as stones, gravel, and concretions was discarded.

Samples were scooped into trays each with 11 PVC cups (capacity 70 mL); a tray was used for nine unknown samples, one standard soil 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 combination diluter-dispensers were used to dispense aliquots of extract or reagent to three samples at a time. Soil samples were analyzed 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.

Exactly 10 mL of soil was scooped into the sample cup and 25 mL of 1 *M* KCl solution was added. The suspension was stirred at 400 r.p.m. for 5 min using multiple stirrers and then allowed to stand for about 30 minutes, and the pH was measured using a gel-filled combination glass electrode while stirring. To measure Ca and Mg, 2.5 mL of soil was scooped into sample cups and 25 mL of 1 *M* KCl solution was added and the suspension was stirred at 400 r.p.m. for 10 min using multiple stirrers. The extracts were filtered using Whatman No.1 paper. The filtrate of 5 mL was diluted with 20 mL of 0.0356 *M* $SrCl_2$, and Ca and Mg were determined by atomic absorption. To determine extractable acidity, 10 mL of the filtrate was diluted with 10 mL of de-ionized water containing 2–4 drops of phenolphthalein and titrated with 0.005 *M* NaOH.

The Ambic-2 extracting solution consists of 0.25 *M* NH_4CO_3 + 0.01 *M* Na_2EDTA + 0.01 *M* NH_4F + 0.05 g L^{-1} Superfloc (N100), adjusted to pH 8 with a concentrated ammonia solution. Twenty-five milliliters of this solution was added to 2.5 mL soil, and the suspension was stirred at 400 r.p.m. for 10 min using multiple stirrers. 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 (1962) molybdenum blue procedure (Hunter, 1974). Potassium was determined by atomic absorption (using an air-acetylene flame) on a 5 mL aliquot of the filtrate after dilution with 20 mL de-ionized water. The remaining undiluted filtrate was used to determine Zn, Cu, and Mn by atomic absorption. Exchangeable Na was determined by atomic absorption after extraction of a 2.5 mL soil sample with 25 mL of 1 *M* ammonium acetate.

Organic carbon, total nitrogen, and clay content were estimated for all soil samples analyzed in the Soil Fertility Laboratory. This was done by mid-infrared reflectance (with a Bruker Tensor 27) using the air-dry, milled soil samples. Total C and N were analyzed using an automated Dumas dry combustion method using a LECO TruSpec CN (LECO Corporation, Michigan, USA; Matejovic, 1996). Briefly, this method involves weighing 0.5-g samples into a tin-foil cup. The crucible was introduced into a vertical furnace, where the sample was burned in a stream of oxygen at 950^{o}C. The gases produced were passed through an infra-red cell where the carbon (as CO_2) is determined. Nitrogen was determined (as N_2) in a thermal-conductivity cell.

Suspended clay and fine silt were determined after dispersion and sedimentation, and sand fractions were determined by sieving. A 20 g soil sample (<2 mm) was treated with hydrogen peroxide to oxidize the organic matter. The sample was made up to 400 mL with de-ionized water and left overnight. The clear supernatant was siphoned off and the sample puddled. Further addition of de-ionized water was added, the sample was stirred and left overnight. The clear supernatant was again siphoned off. Dispersing agents (NaOH and sodium hexametaphosphate) were added, and the sample was stirred on Hamilton Beach stirrers. The suspension was made up to 1 liter in a measuring cylinder and the clay (<0.002 mm) and fine silt (0.002–0.02 mm) fractions were measured with a pipette after sedimentation. Fine silt plus clay was measured after 4–5 min (exact time depends on temperature) at 100 mm, and clay after 5-6 h at a depth of 75 mm. Sand fractions include very fine sand (0.05–0.10 mm), fine sand (0.10–0.25 mm), medium sand (0.25–0.50 mm), and coarse sand (0.50–2.0 mm), which were determined by sieving. Coarse silt (0.02–0.05 mm) was estimated by difference.

3.3 Data collection

The data collection was between September to December of 2018 and 2019, unless mentioned otherwise. Data on vegetative growth was recorded from two selected and tagged plants per pot at 60 days after sowing (DAS) and 60 days after shoot removal (DASR). The following vegetative traits were measured at 60 DAS and 60 DASR; plant height, stem diameter, number of branches per plant, number of leaves per plant, leaf area, shoot mass (fresh and dry) as well as shoot moisture content. Shoots tips were harvested 60 DAS; this pruning was done leaving only the two first true opposite leaves across all 35 pots. Phenological traits such as the number of days to flowering and fruiting were measured upon flower and pod emergence. Seed yield traits such as the number of pods, pod size, number of seeds per pod, and 1000 seed mass were measured at termination 90 days after shoot removal.

3.3.1 Vegetative traits

Plant height (cm) was measured from the soil level to the shoot apex using a ruler at 60 DAS and 60 DASR. The stem diameter (cm) was measured using Vernier callipers at 2 cm above the ground level only at 60 DASR. The numbers of branches and leaves per plant were manually counted at 60 DAS and 60 DASR. Leaf area (cm^2) of the second true leaf set from the ground was measured using a ruler in a non-destructive method using the formula $LA = 0.73(L_L \times W_L)$ (Bvenura and Afolayan, 2013) at 60 DAS. During 60 DASR the leaf area was not measured, the approach of LA measurement was targeting edible potion of the plant, which was 60 prior shoot removal. This was done as a measure of plant biomass before shoot harvest to assess the production and productivity of *Sesamum alatum*. Harvested shoots were allowed to lose excess moisture through wilting for five hours to take fresh mass (g) measurements. The dry mass (g) was achieved by drying the samples at room temperature for 24 hours to lose excess moisture and then the oven (Darvan Brenco Drying oven, Model ODS400) dried at 65 °C until a constant mass was obtained. Both fresh and dry masses were measured using a Denver laboratory scale. The moisture content percentage (MC%) was then calculated using the following formula:

$$Moisture\ content\ \% = \frac{Weight\ before\ dryimg - Weight\ after\ dryimg}{Weight\ before\ drying} \times 100$$

3.3.2 Reproductive traits

The numbers of days to first and (50%) flower and pod formation were determined, respectively. The number of pods per plant was counted directly at 90 days after DASR. At the termination stage, five randomly selected pods per plant were measured for length (mm) and breadth (mm) using Vernier callipers. From the five selected pods, the number of seeds per pod was calculated and the 1000 seed mass in grams (100 seed mass x 10) was determined.

3.4 Data analysis

The raw data on agro-morphological traits were subjected to analysis of variance (ANOVA) using the GLM procedure of Statistical Analysis System (SAS version 9.4). Tukey's Studentized Range test (Honestly Significant Difference) was used to separate treatment means at $P < 0.05$.

3.5 Results

3.5.1 Physicochemical properties of soil and manure

Results on physicochemical properties of composite soils and manures are shown in Table 3.3. The sand soil recorded the highest pH levels (5.72 and 5.94) followed by loam-sand mixture (4.68 and 4.63) with loam soil as the lowest (4.15 and 4.19) in both seasons, respectively. Loam soil recorded the highest phosphorus, potassium, calcium, magnesium, organic carbon, nitrogen, clay, acid saturation, exchangeable acidity, and total cations contents in the first (2018) and second (2019) seasons, respectively. Zinc and copper were high for the loam soil only in the first season and loam-sand mixture in the second season. Manganese was higher in the soil mixture in both seasons. The lowest soil physicochemical properties were recorded from the sandy soil for all seasons.

The manure had a slightly alkaline pH, which ranged from 7.06 to 7.70. Poultry manure had the highest pH (7.70) in season one and goat manure had the highest pH (7.54) in season two. Manure physicochemical composition showed that poultry manure recorded the highest phosphorus, zinc, manganese, and copper compared to goat manure in both seasons. Whereas goat manure had the highest calcium, exchangeable acidity, and total cations contents. Potassium was high in poultry manure during season one but in goat manure during season two. Magnesium was higher for goat manure in the first season but poultry manure in the second season. Total organic carbon, nitrogen, and clay content percentages did not vary for the manures in both seasons, except the clay content in goat manure, which varied between seasons with values (5 and <5%), respectively. Acid saturation percentages were not detected in both manures both seasons.

Table 3.3. Physicochemical properties of the soil and manures.

Parameters	Season One (2018)					Season Two (2019)				
	Soil material			Manure source		Soil material			Manure source	
	Loam	Sand	Sandy-loam	Poultry	Goat	Loam	Sand	Sandy-loam	Poultry	Goat
Sample Density (g/mL)	1.16	1.47	1.43	0.27	0.69	1.20	1.48	1.37	0.43	0.63
Chemical properties										
pH (KCl)	4.15	5.72	4.68	7.70	7.19	4.19	5.94	4.63	7.06	7.54
Organic Carbon (%)	2.6	<0.5	0.5	>6	>6	2.3	<0.5	0.6	>6	>6
Total Nitrogen	0.11	<0.05	<0.05	>0.6	>0.6	0.09	<0.05	<0.05	>0.6	>0.6
Phosphorus	0.0012	0.0003	0.0005	0.0089	0.0035	0.0020	0.0004	0.0015	0.0094	0.005
Potassium	0.0103	0.002	0.003	0.41	0.22	0.11	0.002	0.006	0.27	1.27
Exchangeable cations (mg/L)										
Calcium	585	221	337	791	2966	514	250	340	1241	1773
Magnesium	193	77	112	574	857	170	90	94	997	857
Zinc	4.9	0.7	1.5	72.0	29.3	5.0	0.9	6.4	59.0	18.2
Manganese	22	15	26	62	25	17	14	31	37	10
Copper	2.2	0.6	0.8	4.9	0.9	1.9	0.6	3.7	4.2	0.8
Cation Exchange Capacity										
Acid Saturation (%)	9	4	4	NT	NT	9	4	5	NT	NT
Exch. Acidity (cmol/L)	0.48	0.08	0.10	0.07	0.11	0.39	0.08	0.15	0.08	0.10
Total cations	5.25	2.15	2.79	19.17	27.64	4.59	2.21	2.73	21.27	48.47
Physical properties										
Clay (%)	24	<5	10	<5	5	23	<5	15	<5	<5

NT: not tested

3.5.2 Agrometeorological data

The monthly climatic information on the minimum and maximum temperature, average rainfall, and relative humidity is found in Table 3.3. Temperature data indicated that most first season planting months had lower temperatures than the second season, similarly, the rainfall of season one was lower than season two, which had many rainy days. During the planting months, the highest rainfall (317.78 mm) was received in season two during December. The first season of rainfalls started earlier in the year with the highest of 334. 0 mm and lowest of 12.8 mm. There was high relative humidity for both planting seasons, but that of the first season was lower. The annual climatological information revealed that season one received lower temperatures, lower relative humidity but higher rainfall than the second season.

Table 3.4. Meteorological data of the University of Zululand in 2018 and 2019.

Month	**Temperature (ºC)**				**Rainfall (mm)**		**Relative humidity (%)**	
	2018		**2019**		**2018**	**2019**	**2018**	**2019**
	max.	min.	max.	min.	average	average		
January	31.9	19.9	29.5	19.2	59	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	27	11.1	15	21.6	75	66
August	24.1	13.8	26.3	15.3	89.2	56	75	76
September	26.7	15.4	26.7	14.9	59	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	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**

Source: South African Weather Services, Durban 2021

3.5.3 Vegetative traits

Results on the comparative effects of poultry and goat manure on the vegetative growth of *Sesamum alatum* after 60 days of sowing and shoot removal are presented in Tables 3.5–3.10. Tables 3.5 and 3.6 show the growth variations of each trait between the two planting seasons at 60 days after sowing (DAS) and 60 days after shoot removal (DASR), respectively. The overall response of *S. alatum* to manure soil amendments at 60 DAS and 60 DASR is shown in Tables 3.7 and 3.8, respectively. The seasonal interactive manure performance on studied vegetative traits is summarised in Tables 3.8 and 3.9 for 60 DAS and 60 DASR, respectively. There were significant differences ($P < 0.05$) at 60 DAS in all vegetative traits between the two planting seasons (Table 3.5) and for the number of sub-branches and leaves at 60 DASR (Table 3.6). The second planting season produced the most improved *S. alatum* vegetative traits except for the shoot moisture content at 60 DAS (Table 3.5), the number of small branches, and the number of leaves at 60 DASR (Table 3.6). Manure application significantly increased studied plant parts except for the shoot dry mass and shoot moisture content at 60 DAS (Table 3.7), the number of main branches at 60 DASR, when compared with the control (Table 3.8). The seasonal manure interactive performance shows that the plant height, number of branches, number of leaves, shoot fresh mass and dry mass were significantly increased at 60 DAS (Table 3.9) and this was also recorded for the stem diameter at 60 DASR (Table 3.10).

a. Plant height

The average plant height was higher in the second season than the first season at 60 days after sowing (Table 3.5), but it was similar in both planting seasons at 60 days after shoot removal (Table 3.6). Plants treated with poultry and goat manures were taller than the untreated plants, at both 60 DAS (Table 3.7) and 60 DASR (Table 3.8). Variation in manure type and increase in quantity did not affect the height of *S. alatum* plants at 60 DAS (Table 3.7). However, at 60 DASR, plants treated with 3 t ha^{-1} of goat manure were the tallest (85.05 cm), but they were also similar to the heights of plants that received 2 t ha^{-1} of goat manure as well as 2 and 3 t ha^{-1} of poultry manure (Table 3.8).

The interaction between seasons and manures shows that the application of different types and quantities of manures did not affect plant height in the first season but produced taller plants in the second season when compared with control in each season at 60 DAS (Table 3.9). Plant height ranged from 2.02–5.69 cm and 8.40–24.72 cm in seasons one and two, respectively. In the second season, the tallest plants (24.72 cm) were recorded in 3 t ha^{-1} of goat manure amended soils. However, these plants had a similar height to those that received 1 and 2 t ha^{-1} of poultry manure, and 2 t ha^{-1} of goat manure.

At 60 DASR, plant height varied between 54.9 cm (control) and 91.1 cm (3 t ha^{-1} goat manure) in the first season, and between 49.2 cm (control) and 79.4 cm (2 t ha^{-1} goat manure) in the second season (Table 3.10). The tallest plants recorded in 3 t ha^{-1} of goat manure treatment, in season one, were similar to those treated with 2 t ha^{-1} of poultry manure as well as 1 and 2 t ha^{-1} of goat manure. Again, in season one, all manure treatments produced plants with a height similar to the control, except for 3 t ha^{-1} of goat manure. In the second season, all plants exposed to different types and quantities of manure had similar heights. Among these, only plants exposed to 3 t ha^{-1} of poultry manure as well as 2 and 3 t ha^{-1} of goat manure, were taller than control.

Table 3.5 Response of vegetative traits to seasonal variation in poultry and goat manure treated *Sesamum alatum* plants.

Seasons	60 days after sowing							60 days after shoot removal				
	PH	NB	NL	LA	SFM	SDM	SMC%	PH	SD	NMB	NSB	NL
One	3.80 [b]	1.47 [b]	6.16 [b]	6.62 [b]	0.84 [b]	0.15 [b]	83.47 [a]	71.76	0.46	1.84	22.37 [a]	99.40 [a]
Two	18.63 [a]	9.47 [a]	31.31 [a]	8.51 [a]	2.69 [a]	0.60 [a]	76.06 [b]	68.19	0.48	1.94	18.61 [b]	65.71 [b]
Significance	***	***	***	***	***	***	***	NS	NS	NS	**	***

PH, plant height (cm); NB, number of branches per plant; NL, number of leaves; LA, leaf area (cm^2); SFM, shoot fresh mass (g); SDM, shoot dry mass (g); SMC%, shoot moisture content percentage; SD, stem diameter (cm); NMB, number of main branches per plant; NSB, number of sub-branches per plant. Different superscript(s) within a column indicate significant differences according to Tukey's Studentized Range (HSD) ($P<0.05$). Significance level: NS, not significant; ** $P < 0.01$; *** $P < 0.001$.

Table 3.6. Effect of poultry and goat manure on *Sesamum alatum* vegetative traits (n = 10).

Manure	Rate (t/ha)	60 days after sowing							60 days after shoot removal				
		PH	NB	NL	LA	SFM	SDM	SMC%	PH	SD	NMB	NSB	NL
Control	0	5.21 [b]	3.10 [b]	12.10 [c]	4.54 [b]	0.71 [b]	0.22 [b]	79.12 [ab]	52.05 [c]	0.37 [d]	1.70 [b]	13.75 [c]	61.10 [c]
Poultry	1	11.58 [a]	5.10 [a]	17.90 [b]	7.61 [a]	1.28 [ab]	0.30 [a]	75.25 [b]	65.50 [b]	0.45 [bc]	1.90 [ab]	20.25 [abc]	86.90 [abc]
	2	11.61 [a]	5.80 [a]	19.70 [ab]	8.30 [a]	1.90 [ab]	0.39 [a]	80.56 [ab]	71.35 [ab]	0.48 [abc]	1.75 [ab]	18.85 [c]	78.35 [abc]
	3	11.57 [a]	6.40 [a]	19.85 [ab]	8.28 [a]	2.23 [a]	0.41 [a]	82.43 [a]	70.85 [ab]	0.49 [ab]	1.80 [ab]	18.20 [c]	81.40 [abc]
Goat	1	11.07 [a]	5.75 [a]	19.10 [ab]	7.26 [a]	1.59 [ab]	0.33 [a]	79.33 [ab]	68.55 [b]	0.43 [c]	1.80 [ab]	18.90 [bc]	70.35 [bc]
	2	13.40 [a]	6.20 [a]	19.70 [ab]	8.68 [a]	2.30 [a]	0.47 [a]	81.56 [ab]	70.85 [ab]	0.51 [a]	1.95 [ab]	26.80 [a]	100.85 [a]
	3	14.08 [a]	5.95 [a]	22.80 [a]	8.31 [a]	2.33 [a]	0.46 [a]	79.85 [ab]	85.05 [a]	0.53 [a]	2.35 [a]	26.70 [ab]	98.95 [ab]
Significance		***	***	***	***	**	*	NS	***	***	*	***	**

PH, plant height (cm); NB, number of branches per plant; NL, number of leaves; LL, leaf length (cm); LW, leaf width (cm); LA, leaf area (cm^2); SFM, shoot fresh mass (g); SDM, shoot dry mass (g); SMC%, shoot moisture content percentage; SD, stem diameter (cm); NMB, number of main branches per plant; NSB, number of sub-branches per plant. Different superscripts within a column indicate significant differences in Tukey's Studentized Range (HSD) ($P<0.05$). Significance level: NS, not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Table 3.7. Interaction between season and manure on vegetative traits of *Sesamum alatum*.

Season	Manure	Rate (t/ha)	60 days after sowing PH	NB	NL	LA	SFM	SDM	SMC%	60 days after shoot removal PH	SD	NMB	NSB	NL
One	**Control**	**0**	2.02 ^{d}	0.6 ^{c}	4.8 ^{d}	3.98	0.35 ^{e}	0.18 ^{dc}	83.40 ^{a}	54.9	0.37 ^{f}	1.8	14.9	75.7
	Poultry	**1**	3.65 ^{dc}	1.3 ^{c}	6.0 ^{d}	7.23	0.91 ^{cde}	0.13 ^{d}	83.25 ^{a}	67.0	0.47 $^{b-e}$	1.7	24.5	103.0
		2	3.42 ^{dc}	2.0 ^{c}	6.4 ^{d}	7.26	1.11 ^{cde}	0.15 ^{d}	85.99 ^{a}	74.0	0.49 $^{a-d}$	1.7	20.3	92.7
		3	4.18 ^{dc}	1.8 ^{c}	6.3 ^{d}	7.34	1.11 ^{cde}	0.16 ^{dc}	84.76 ^{a}	68.3	0.46 $^{b-f}$	1.6	17.6	91.8
	Goat	**1**	4.18 ^{dc}	1.7 ^{c}	6.8 ^{d}	6.07	0.62 ^{de}	0.12 ^{d}	80.66 ^{a}	73.5	0.44 $^{c-f}$	1.5	19.0	80.8
		2	5.69 ^{dc}	2.2 ^{c}	7.0 ^{d}	8.03	0.86 ^{cde}	0.13 ^{d}	85.53 ^{a}	73.5	0.46 $^{b-f}$	2.5	29.9	122.6
		3	3.43 ^{dc}	0.7 ^{c}	5.8 ^{d}	6.47	0.93 ^{cde}	0.16 ^{dc}	80.73 ^{a}	91.1	0.51 $^{a-d}$	2.1	30.4	129.2
Two	**Control**	**0**	8.40 ^{c}	5.6 ^{b}	19.4 ^{c}	5.10	1.06 ^{cde}	0.27 ^{bcd}	74.82 ^{ab}	49.2	0.372 ^{ef}	1.6	12.6	46.5
	Poultry	**1**	19.50 ^{ab}	8.9 ^{a}	29.8 ^{b}	8.00	1.66 $^{b-e}$	0.48 $^{a-d}$	67.24 ^{b}	64.0	0.44 $^{c-f}$	2.1	16.0	70.8
		2	19.80 ^{ab}	9.6 ^{a}	33.0 ^{ab}	9.34	2.69 ^{abc}	0.63 ^{ab}	75.72 ^{ab}	68.7	0.47 $^{b-e}$	1.8	17.4	64.0
		3	18.95 ^{b}	11.0 ^{a}	33.4 ^{ab}	9.21	3.35 ^{ab}	0.65 ^{ab}	80.11 ^{a}	73.4	0.52 ^{abc}	2.0	18.8	71.0
	Goat	**1**	17.95 ^{b}	9.8 ^{a}	31.4 ^{b}	8.46	2.57 $^{a-d}$	0.56 ^{abc}	78.00 ^{ab}	63.6	0.42 ^{def}	2.1	18.8	59.9
		2	21.10 ^{ab}	10.2 ^{a}	32.4 ^{b}	9.33	3.75 ^{a}	0.81 ^{a}	77.60 ^{ab}	79.4	0.57 ^{a}	2.2	23.7	79.1
		3	24.72 ^{a}	11.2 ^{a}	39.8 ^{a}	10.15	3.72 ^{a}	0.77 ^{a}	78.97 ^{a}	79.0	0.54 ^{ab}	1.8	23.0	68.7
Significance			***	**	***	NS	*	*	*	NS	**	NS	NS	NS

PH, plant height (cm); NB, number of branches per plant; NL, number of leaves; LA, leaf area (cm^2); SFM, shoot fresh mass (g); SDM, shoot dry mass (g); SMC%, shoot moisture content percentage; SD, stem diameter (cm); NMB, number of main branches per plant; NSB, number of sub-branches per plant. Different superscript(s) within a column indicate significant differences according to Tukey's Studentized Range (HSD) ($P<0.05$). Significance level: NS, not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

b. Stem diameter

Stems of *Sesamum alatum* were very delicate and weak in the early stages of plant growth, thus the stem diameter was only measured at 60 DASR. The stem diameter obtained in both seasons was similar, with values 0.46 and 0.48 cm, respectively (Table 3.6). Poultry and goat manure amended soil increased the overall stem thickness (Table 3.8). Plants that received 2 and 3 t ha^{-1} of goat manure had the thickest stems, which were similar to plants exposed to 2 and 3 t ha^{-1} of poultry manure (Table 3.8). The highest stem diameter was recorded in season two with 2 t ha^{-1} of goat manure-treated plants. However, similar stem diameters were recorded with 2 t ha^{-1} of poultry manure and 3 t ha^{-1} of goat manure in the first season, and 3 t ha^{-1} of poultry and goat manure in the second season (Table 3.10). The thinnest stems recorded from control plants in season one were similar to those recorded with 3 t ha^{-1} of poultry manure, 1 and 2 t ha^{-1} of goat manure treated plants (Table 3.10). In season two, the control recorded comparable thinner stems as plants that were exposed to 1 and 2 t ha^{-1} of poultry manure as well as 1 t ha^{-1} of goat manure.

c. Number of branches

Numerous branches were recorded in season two at 60 days after sowing (Table 3.5). At 60 days after shoot removal, the number of main branches was similar for both seasons whereas the number of sub-branches was higher in season one (Table 3.6). Poultry and goat manure increased the number of branches per plant when compared with control at 60 DAS (Table 3.7). However, at 60 DASR, this increase was only obtained with the application of 3 t ha^{-1} of goat manure for main branches whose effect was significantly similar to the rest of the manure application rates (Table 3.8). The number of sub-branches was greatly increased with 2 t ha^{-1} of goat manure whose effect was not different from 1 t ha^{-1} of poultry manure and 3 t ha^{-1} of goat manure (Table 3.8). Variations in manure types and application levels did not affect the number of branches at 60 DAS and main branches at 60 DASR.

The application of different types and quantities of manures did not affect the number of branches at 60 DAS in season one but produced numerous branches in season two when compared with control (Table 3.9). The number of main branches per plant was not affected by manure application in both seasons. A higher number of sub-branches was recorded from plants treated with 2 and 3 t ha^{-1} of goat manure when compared with control in the first season at 60 DASR (Table 3.10).

d. Number of leaves

The average number of leaves was higher in the second season than the first season at 60 days after sowing (Table 3.5), conversely, at 60 days after shoot removal, the leaf number was higher in season one (Table 3.6). Manure-treated plants recorded numerous leaves compared with control plants, at 60 DAS (Table 3.7). However, at 60 DASR the highest number of leaves was obtained with 2 and 3 t ha^{-1} of goat manure but were similar to all poultry manure application rates (Table 3.8). The differences in manure types and application levels affected the number of leaves at both 60 DAS and 60 DASR. Plants treated with 1 t ha^{-1} of poultry manure recorded the least number of leaves compared to 3 t ha^{-1} of goat manure at 60 DAS (Table 3.7). At 60 DASR, plants treated with 1 t ha^{-1} of goat manure recorded the least number of leaves only when compared with 2 t ha^{-1} of goat manure (Table 3.8).

In the second season, manure-treated plants produced numerous leaves when compared with control in each season, at 60 DAS (Table 3.9). Leaf numbers ranged between 4.8–7.6 leaves and 19.4–39.8 leaves in seasons one and two, respectively. The highest number of leaves per plant (39.8) was recorded with 3 t ha^{-1} of goat manure in the second season but was similar to plants exposed to 2 and 3 t ha^{-1} of poultry manure (Table 3.10). At 60 DASR, the number of leaves ranged from 95.7–129.2 in the first season, and between 46.5–79.1 in the second season (Table 3.10). In season one, the number of leaves per plant recorded in 3 t ha^{-1} of goat manure was higher compared with control but comparable to all other treatment rates. Again, in season one, the control was also comparable with all other manure treatments except for 3 t ha^{-1} of goat manure. In the second season, all plants exposed to different types and quantities of manure had a similar number of leaves per plant. However, plants exposed to 2 t ha^{-1} of goat manure had more leaves than other treatment rates (Table 3.10).

e. Leaf size

The average leaf length, width, and area were higher in season two compared to season one (Table 3.5). The longest, broadest, and biggest leaves were produced by plants treated with poultry and goat manures than control (Table 3.7). Variation in manure types and application levels did not affect *S. alatum* leaf length, width, and area (Table 3.7). Manure-treated plants recorded the longest and broadest leaves in both seasons except for plants that were treated with 1 t ha^{-1} of goat manure in season one. The control plants had the shortest and narrowest leaves in both seasons. The biggest leaves were recorded in manure-treated plants than control plants across seasons except for 1 and 3 t ha^{-1} of goat manure-treated plants in season one. The leaf length varied between 3.01 cm (control) and 4.07 cm (2 t ha^{-1} goat manure) in season one and 3.53 (control) to 4.78 cm (3 t ha^{-1} goat manure) in season two. The leaf width ranged from 1.80 cm (control) to 2.68 cm (2 t ha^{-1} goat manure) in season one and 1.97 cm (control) to 2.90 cm (3 t ha^{-1} goat manure) in season two. The leaf area (cm^2) ranged from 5.31–11.00 and 6.99–13.90 in seasons one and two, respectively.

f. Shoot mass

The average shoot fresh and dry mass was higher in the second planting season than in the first season (Table 3.5). Plants treated with poultry and goat manure had a heavier shoot mass when compared with control (Table 3.7). Variation in manure types and quantities did not affect the shoot masses of *S. alatum* (Table 3.7). In the second season, the shoot fresh mass was higher at 2 and 3 t ha^{-1} of goat manure but comparable to 1 t ha^{-1} of goat manure as well as 2 and 3 t ha^{-1} of poultry manure when compared with control (Table 3.9). The shoot dry mass was also heavy with 2 and 3 t ha^{-1} of goat manure treated plants but was similar with 1 t ha^{-1} of goat manure and all poultry manure quantities (Table 3.9).

The shoot dry mass varied between 0.12 g (1 t ha^{-1} goat manure) and 0.18 g (control) in season one and between 0.27 g (control) and 0.81 g (2 t ha^{-1} goat manure) season two (Table 3.9). Plants exposed to 2 and 3 t ha^{-1} of goat manure recorded the highest shoot dry masses (0.81 and 0.77 g) in season two, which were comparable to all manure-treated plants (Table 3.9).

g. Shoot moisture content

The average shoot moisture content was higher in season one compared to season two (Table 3.5). Plants treated with poultry and goat manures had a similar shoot moisture content as the control (Table 3.7). The interaction between seasons and manures shows that the application of different types and quantities of manures did not affect shoot moisture content across seasons (Table 3.9). Shoot moisture content ranged from (80.66–85.99%) and (67.24–80.11%) in seasons one and two, respectively.

3.5.4 Reproductive traits

Figures 3.3 and 3.4 represent the effect of poultry and goat manure on the number of days to first and (50%) flower as well as pod formation in *Sesamum alatum*, respectively. Results on the comparative effect of poultry and goat manure on the reproductive traits of *Sesamum alatum* at 60 days after shoot removal are presented in Tables 3.11–3.13. Numerous pods were recorded in season two, whereas thicker pods were produced in season one (Table 3.11). There were significant differences in the reproductive traits of manure-treated plants when compared with control, the highest pod number, seed number per pod, and biggest pod size were produced with manure (Table 3.12). The interactions between manures and seasons show that the application of different types of manures and quantities caused no significant increase to all measured reproductive traits except the pod number (Table 3.13).

a. Number of days to flower formation

Sesamum alatum flowered earlier in manure treated plants at 83 days, which was comparable to control plants, which flowered at 89 days in season one (Figure 3.3 a). In season two, plants that were treated with 3 t ha^{-1} of poultry and goat manure flowered early (83 days), which was similar to plants that received 1 t ha^{-1} of goat manure (84 days) (Figure 3.3 b). Again, in season two, control plants flowered on the same day as plants that were subjected to 1 and 2 t ha^{-1} of poultry manure and 2 t ha^{-1} of goat manure (Figure 3.3 b). The earliest (50%) flower formation was produced with 1 t ha^{-1} of poultry and goat manure at 83 days in season one (Figure 3.3 a). This was comparable with the number of days (84 days) to (50%) flower formation recorded in 2 and 3 t ha^{-1} of poultry manure, which was also similar to 2 and 3 t ha^{-1} of goat manure (85 days) (Figure 3.3 a). In season two, plants that received goat manure at 1 t ha^{-1} produced (50%) of flowers earlier (87 days), which was similar to 2 and 3 t ha^{-1} of goat manure and 3 t ha^{-1} of poultry manure (88 days), but 1 and 2 t ha^{-1} of poultry manure flowered at 89 days. Control plants recorded a delayed (50%) flower formation in both seasons (Figure 3.3 a–b).

b. Number of days to pod formation

The earliest pod was obtained with 1 t ha^{-1} of goat manure at 89 days, this was similar to all other treatment rates (90 days) in season one (Figure 3.4 a). In season two, 3 t ha^{-1} of poultry and goat manure treated plants had an early pod formation, which was similar to that of poultry manure (1 and 2 t ha^{-1}) and goat manure at 1 t ha^{-1} (Figure 3.4 b). Control plants had delayed pod formation in season two (Figure 3.4 b). Manure-treated plants had the earliest and same number of days (91) to (50%) pod formation compared with control (95 days) in season one (Figure 3.4 a). The lowest number of days to (50%) pod formation was recorded with 3 t ha^{-1} of poultry and goat manure at 93 days (Figure 3.4 b). A similar number of days to (50%) pod formation was recorded with 1 and 2 t ha^{-1} of poultry manure as well as 1 t ha^{-1} of goat manure in season two (Figure 3.4 b). Plants that received no manure treatment had delayed (50%) pod formation in season two (Figure 3.4 b).

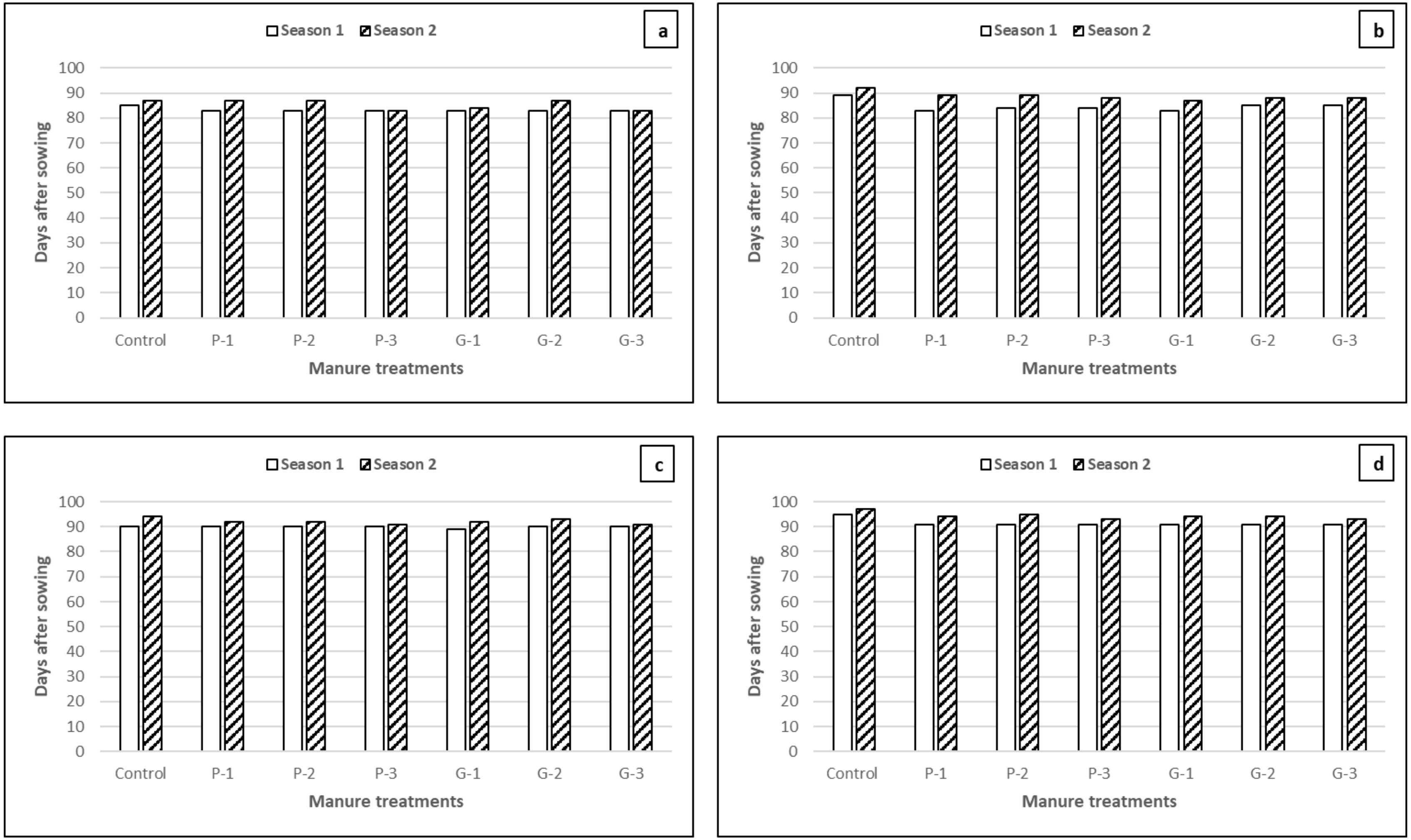

Figure 3.3. The number of days to the first flower (a), (50%) flower (b), first pod (c), and (50%) pod (d) formation of *Sesamum alatum* as influenced by poultry and goat manure during first and second seasons. Manure treatments: Control, No manure; P, poultry manure; G, goat manure; 1, 2 and 3, one, two, and three tons per hectare**.**

c. Number of days to pod formation

The earliest pod was obtained with 1 t ha^{-1} of goat manure at 89 days, this was similar to all other treatment rates (90 days) in season one (Figure 3.4 a). In season two, 3 t ha^{-1} of poultry and goat manure treated plants had an early pod formation, which was similar to that of poultry manure (1 and 2 t ha^{-1}) and goat manure at 1 t ha^{-1} (Figure 3.4 b). Control plants had delayed pod formation in season two (Figure 3.4 b). Manure-treated plants had the earliest and same number of days (91) to (50%) pod formation compared with control (95 days) in season one (Figure 3.4 a). The lowest number of days to (50%) pod formation was recorded with 3 t ha^{-1} of poultry and goat manure at 93 days (Figure 3.4 b). A similar number of days to (50%) pod formation was recorded with 1 and 2 t ha^{-1} of poultry manure as well as 1 t ha^{-1} of goat manure in season two (Figure 3.4 b). Plants that received no manure treatment had delayed (50%) pod formation in season two (Figure 3.4 b).

d. Number of pods

The pod number was higher (14.56) in season two when compared with season one (Table 3.8). Plants that were supplied with poultry and goat manure produced numerous pods than control plants (Table 3.8). Variation in source and quantity of manure application affected the number of pods per plant, hence goat manure had the highest number of pods compared to poultry manure (Table 3.8). The interaction between seasons and manures shows that the application of different types and quantities of manures affected the number of pods in both seasons (Table 3.8). There was a gradual increase in the pod number with increased manure quantities in both seasons. Pod numbers ranged from 6.3–13.0 and 7.0–18.5 in seasons one and two, respectively. The highest number of pods was obtained with 3 t ha^{-1} of goat manure in season one and 2 t ha^{-1} of goat manure in season two, which were similar to 3 t ha^{-1} of poultry manure and 1 t ha^{-1} of goat manure (Table 3.8).

e. Pod length and diameter

A similar pod length was recorded in both seasons, whereas the pod diameter was higher in season one than in season two (Table 3.8). Plants that received poultry and goat manure resulted in longer and thicker pods compared with plants that received no manure. Manure and application rates variations show that 1 t ha^{-1} of poultry manure treated plants produced a lower pod size than that of plants treated with goat manure (Table 3.8). Seasons and manure interaction show that the application of different manure types and quantities increased the pod length except for 1 t ha^{-1} of poultry manure in both seasons. This increase was only obtained in season one in the pod diameter (Table 3.8). The pod length varied between 3.99 cm (control) and 4.66 cm (1 t ha^{-1} goat manure) in season one and 3.83 (control) to 4.56 cm (3 t ha^{-1} goat manure) in season two. Whereas the pod diameter ranged from 0.50–0.58 cm and 0.50–0.56 cm in seasons one and two, respectively.

f. Number of seeds

The number of seeds recorded in both seasons was similar, with values 76.70 and 75.40, respectively (Table 3.8). Plants that were exposed to manure had numerous seeds than control plants, with the highest recorded in 3 t ha^{-1} of goat manure, which was similar to 3 t ha^{-1} of poultry manure as well as 1 and 2 t ha^{-1} of goat manure (Table 3.8). Lower rates of poultry manure (≤2 t ha^{-1}) recorded a similar number of seeds but 1 t ha^{-1} was also comparable with the control, which had the lowest seed number (Table 3.8). The interaction between seasons and manures shows that goat manure had a higher seed number compared with the control in both seasons. However, the number of seeds obtained with poultry manure (≤2 t ha^{-1}) was comparable to the control but higher rates (≥2 t ha^{-1}) were similar to goat manure in both seasons (Table 3.8).

Table 3.8. Effect of season and manure on reproductive traits of *S. alatum*.

Season	Rate (t/ha)	NP	PL	PW	NSP	1000SM
One		9.57 b	4.39	0.55 a	76.70	1.34
Two		14.56 a	4.33	0.53 b	75.40	1.27
Significance		***	NS	*	NS	NS
Manure						
Control	0	6.65 c	3.91 c	0.50 b	65.40 c	1.47 a
Poultry	1	10.20 b	4.16 b	0.50 b	69.90 bc	1.36 ab
	2	10.30 b	4.41 a	0.54 ab	73.55 b	1.28 ab
	3	14.05 a	4.43 a	0.56 a	80.00 a	1.29 ab
Goat	1	13.00 ab	4.58 a	0.57 a	80.05 a	1.25 ab
	2	14.80 a	4.52 a	0.55 a	80.30 a	1.27 ab
	3	15.45 a	4.53 a	0.56 a	83.15 a	1.20 b
Significance		***	***	***	***	*
Season x Manure						
Control (S1)	0	6.3 f	3.99	0.50	67.9	1.50
Poultry (S1)	1	8.2 def	4.21	0.51	69.6	1.45
	2	8.1 def	4.48	0.56	74.0	1.29
	3	9.8 c-f	4.37	0.58	79.9	1.34
Goat (S1)	1	10.5 c-f	4.66	0.58	79.9	1.30
	2	11.1 b-e	4.55	0.55	80.8	1.28
	3	13.0 bc	4.49	0.56	84.8	1.22
Control (S2)	0	7.0 ef	3.83	0.50	62.9	1.44
Poultry (S2)	1	12.2 bcd	4.11	0.50	70.2	1.27
	2	12.5 bcd	4.33	0.52	73.1	1.27
	3	18.3 a	4.48	0.54	80.1	1.23
Goat (S2)	1	15.5 ab	4.50	0.56	80.2	1.21
	2	18.5 a	4.49	0.55	79.8	1.26
	3	17.9 a	4.56	0.56	81.5	1.18
Significance		**	NS	NS	NS	NS

NP, number of pods per plant; NSP, number of seeds per pod; PL, pod length (cm); PD, pod diameter (cm); 1000SM, thousand seed mass (g). Different superscripts within a column indicate significant differences in Tukey's Studentized Range (HSD) ($P<0.05$). Significance level: NS, not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

f. Seed mass

The seed mass was similar in both planting seasons (Table 3.8). Only *Sesamum alatum* plants that had no manure recorded heavier seed mass compared with 3 t ha^{-1} of poultry manure but the variation in manure types and quantities did not affect the seed mass (Table 3.8). The interaction in seasons and manures showed that variations in manure types and application levels did not affect the seed mass across seasons (Table 3.8). Seed mass ranged from 1.22–1.50 g and 1.18–1.44 g in seasons one and two, respectively (Table 3.8).

3.6 Discussion

3.6.1 Physicochemical properties of soil and manure

The experimental soils were moderately acidic, the pH ranged between 4.15–5.94. The loam soil had the lowest, followed by sandy-loam soil whereas sand soil had the highest pH values in seasons one and two, respectively. Sandy-loam soil used in the present study had lower pH compared to the sandy-loam soil used in the University of Ilorin in Nigeria to grow *S. indicum* (Eifediyi et al., 2018) but they were higher than those reported at the University of Nigeria, Nsukka (Ogbonna and Umar-Shaaba, 2012). Soil pH is one of the influential factors in the soil nutrient availability of agricultural lands. Acidic plant growing media are known to have calcium and magnesium deficiency, whereas basic media results in iron and phosphorus deficiency (Mathowa et al., 2014). The poultry and goat manure used in the current study was slightly alkaline (7.06–7.70), which indicates that they can neutralize the acidic growing media used in the current study.

Animal manures can stabilise unfavourable soil pH fluctuations by adding substantial organic matter, which improves nutrient absorption by plants (Adediran et al., 2015; Ayinla et al., 2018; Eifediyi et al., 2018). The application of organic manures on agricultural land buffers soil pH for plant growth and improved crop production (Haruna, 2011; Eifediyi et al., 2018). Soil pH buffering may be attributed to the fact that organic manures increase the availability and absorption of P in the soil (Mkhabela, 2006; Adediran et al., 2015) by reducing P adsorption and activating natural soil P and improving the biological, chemical, and physical composition of the soil (Mkhabela, 2006). Furthermore, the KwaZulu-Natal soils have been identified to have P sorption or fixation problems among other South African soils used for farming (Mkhabela, 2006; Materechera, 2010).

The chemical properties of sandy-loam soil and poultry manure used in the current study were richer compared to the results reported at the University of Nigeria from the evaluation of *S. indicum* growth and yield (Ogbonna and Umar-Shaaba, 2011). However, the sandy-loam soil used at the University of Ilorin to grow *S. indicum* had high phosphorus (6.20 mg/kg), potassium (54,6 mg/kg) only in season one, and high magnesium (936 mg/kg) in season two, the calcium (585 and 897 mg/kg), organic carbon (1.00 and 1.78 g/kg), nitrogen (1.14 and 1.13 g/kg), and pH levels (5.6 and 6.1) were all high in both planting seasons (Eifediyi et al., 2018) when compared to the sandy-loam soil of the current study (Table 3.3). Total organic carbon and N contents of the present sandy-loam soil were higher than quantities reported in Sokoto state of northwestern Nigeria to grow *S. indicum* (Taimiyu et al., 2012). The manganese contents (26 and 31 mg/L) reported in the sandy-loam soil of the present study were below 50 ppm, which is the average manganese intake for plants but within the recommended intake range limits (20–200 ppm) desired for optimum Mn metabolic function (Mahler, 2004). Manganese importance in plants is often neglected in literature and soil nutrient analysis. Even so, Mn has exclusively been required in the oxygen-evolving complex of photosynthesis II and Mn superoxide dismutase, which enhances plant healthy and cell division (Alejandro et al., 2020).

The analysis of goat manure's physical and chemical properties used in the present study showed richer nutrient contents than the goat manure that was used in South-eastern Nigeria to grow *Abelmoschus esculentus* (Chinatu and Okoronkwo, 2016), and *Corchorus olitorius* (Garjila et al., 2017). Richer goat manure chemical properties were reported in Eastern Cape in a study on *Solanum nigrum* mineral intake (Bvenura and Afolayan, 2014). Goat manure had a higher Ca content compared to poultry manure (Table 3.3). This is similar to Awodun et al. (2007), who also reported high Ca quantities in goat manure than poultry manure. The manures used in the current experiment had high P and K but low in organic carbon and N compared to poultry and goat manures used to cultivate *S. indicum* in Indonesia (Nurhayati et al., 2012). Plants growth and development require a range of soil nutrients and they must be supplied within plant intake limits. Nitrogen, organic matter, phosphorus, and potassium are determining factors of soil productiveness and organic manure has been used to improve soil nutrients and ultimately improve crop production (Eifediyi et al., 2018).

Nitrogen is an essential macronutrient for plant greenness, proteins, amino acids, and nucleic acid, which are central building blocks in plant growth and development (Muñoz-Huerta et al., 2013). A large portion of up to (50%) of all nutrient contribution in plant growth is nitrogen dependent (Babajide and Oyeleke, 2014). When supplied within limits, N increases the photosynthetic activities of the plant by increasing the leaf area, chlorophyll content, carboxylases as well as leaf weight, which control dry matter (Babajide and Oyeleke, 2014). However, nitrogen dosages that are not within limits could cause plant growth disturbances and initiate plant toxicity (Ranadheera et al., 2017). For example, high N levels may increase nitrate accumulation, which is harmful to human consumption (Babajide and Oyeleke, 2014; Liu et al., 2014), whereas nitrogen deficiency results in low cell division, chlorosis, reductions in flowers, seed protein content and accelerates aging in plants (Uchida, 2000).

The physicochemical analysis of used manure depicts substantially higher nutrient composition compared to sandy-loam soil used as control growing media. Similar results were also reported in a study conducted to assess the effects of various types of manure on agro-morphological traits and nutrient configuration of *Corchorus olitorious* in Nigeria (Ayinla et al., 2018). This indicates that organic manures can recover the soil structure by increasing soil nutrient status through mineralisation (Law-Ogbomo and Osaigbovo, 2016; Ayinla et al., 2018).

3.6.2 Effect of poultry and goat manure on vegetative growth of *S. alatum*

The experimental design carried out during the study was the same, yet there were differences in the agro-morphological traits of *S. alatum* between both seasons. The results showed significant variations in growth between the seasons at 60 days after sowing (DAS) for all measured traits (Table 3.5). This variation was also observed at 60 days after shoot removal (DASR) between the number of sub-branches and the number of leaves (Table 3.6). These dissimilarities in agro-morphological traits expression could be attributed to meteorological factors such as rainfall and temperature variations (Haruna, 2011; Eifediyi et al., 2018). There was less rainfall received during the first season of the planting months compared to the second season, but there were similarities in both the maximum and minimum temperatures of both seasons (Table 3.4). Increased plant height, branch number, leaves, leaf size and shoot matter at 60 DAS in season two (2019) planting months (Table 3.5) may be associated with the high rainfalls received (Table 3.3). This increased number of branches and leaves was also consequent at 60 DASR (Table 3.6). Though *Sesamum* plants are regarded as drought-tolerant plants, they can also be highly productive under relatively high temperatures and moderate rainfall (Eifediyi et al., 2018).

The application of poultry and goat manure significantly increased plant height, the number of branches and leaves per plant, leaf size (length, width, and area), and plant matter (shoot fresh and dry mass) in *Sesamum alatum* at 60 DAS (Table 3.7). A similar increase with manure application was obtained in the stem diameter at 60 DASR. The application of 2 and 3 t h^{-1} of goat manure produced higher vegetative growth improvements in *S. alatum* compared to the other quantities and types of applied manures. Most vegetative attributes increased when the manure application rate increased from 1 to 2 and 3 t h^{-1} in the two planting seasons. A similar increase in vegetative growth traits with increasing organic manure rates was reported in *S. indicum* (Haruna, 2011; Eifediyi et al., 2018) and *C. olitorius* (Tovihoudji et al., 2015).

Organic manure nutrients increased with quantity, hence increasing levels of application resulted in greater vegetative growth improvements. The application of organic manure improves the soil physicochemical by recycling nutrients and activating the microbiological biomass of the soil, which ultimately increases the plant growth and productivity (Tovihoudji et al., 2015; Khandaker et al., 2017). Organic manures support the soil microbial biomass, which produces phytohormones that act as plant growth stimulators and assist in nutrient uptake (Fonge et al., 2016). This soil nutrient enhancement and crop productiveness when poultry manure was applied were evident in *Sesamum indicum* studies (Akande et al., 2011; Usman et al., 2016; Ndor and Nasir, 2019). Furthermore, an increased vegetative growth was also reported in *Amaranthus dubius* (Ahmad et al., 2019), *Amaranthus cruentus* (Akparobi, 2009), *Corchorus olitorius* (Musa et al., 2020), and *Abelmoschus esculentus* (Khandaker et al., 2017) when organic manures were applied.

Crop productiveness is dependent on soil fertility, which varies largely with soil organic matter, available nitrogen (Babajide and Oyeleke, 2014; Kaburi, 2015; Eifediyi et al., 2018), phosphorus, and potassium (Eifediyi et al., 2018). This increase in soil organic matter, Ca, Mg, N, P, and K for improved crop production was reported in a study conducted to evaluate the effect of goat manure on *Capsicum annuum* growth and yield (Awodun et al., 2007). Poultry manure improves the structure and increases essential nutrients of the soil (Eifediyi et al., 2018). Nitrogen is responsible for photosynthesis and vegetative growth (Adediran et al., 2015), as well as feeding the microbial life cycle in the soil (Fonge et al., 2016). Higher quantities of poultry and goat manure could have increased the soil organic matter, nitrogen, phosphorus, and potassium more sufficiently than lower quantities of applied manure.

a. Plant height

Sesamum alatum plants were significantly taller in the second planting season compared to the first season at 60 DAS (Table 3.5). Contrary to a similar study that was done in the University of Nigeria on *S. indicum,* which showed that the first season had the tallest plants compared to the second season (Ogbonna and Umar-Shaba, 2012). This was due to the differences in soil Ph, which showed more stable pH levels and low cation exchange capacity in the first plant season compared to the second. Whereas, the increase in *S. alatum* plant height may be attributed to increased levels of P, K, Ca, Zn, Mn, Cu, and organic carbon of the soil mixture and manure used in season two (Table 3.3) and/or high rainfall and adequate temperatures received during season two planting months (Table 3.4). *Sesamum indicum* can grow both under dry and wet climatic weather conditions, but better plant growth performance has been reported in moderate rainfalls and fairly high temperatures (Eifediyi et al., 2018).

The plant height of *Sesamum alatum* plants exposed to poultry and goat manure differed significantly at 60 DAS (Table 3.7) and 60 DASR (Table 3.8) when compared with plants that did not receive manure treatment. This significant increase in plant height was reported in *Sesamum indicum* plants with poultry manure (Akande et al., 2011; Usman et al. 2016). The application of poultry manure also significantly increased the plant height of *Abalmoschus esculentus* (Tiamiyu et al., 2012). Poultry manure provides essential physical, chemical, and biological improvements to the soil, which enhances plant growth and development (Haruna, 2011; Ogbonna and Umar-Shaaba, 2012; Eifediyi et al., 2018). Manure used had sufficient quantities of effective physicochemical properties for the enhancement of *S. alatum* meristematic activities. Goat manure also significantly increased the plant height in *Amaranthus hybridus* (Ekwealor et al., 2020) and *Corchorus olitorius* (Law-Ogbomo and Osaigbovo et al., 2016; Garjila et al., 2017).

Increasing poultry and goat manure concentrations had a direct effect on plant tallness. The tallest plants when poultry manure was applied were produced at 2 t ha^{-1}, whereas goat manure produced the tallest plants at 3 t ha^{-1}. Low concentrations of poultry manure are known to produce taller *S. indicum* plants than higher concentrations (Akande et al., 2011). This decrease in plant height with increased poultry manure application levels is reported in many other similar agro-morphological studies of *Amaranthus cruentus* L. (Maerere et al., 2001), *Abelmoschus Esculentus* L.Moench. (Khandaker et al., 2017), *Corchorus olitorius* L. (Tovihoudji et al., 2015; Law-Ogbomo and Osaigbovo, 2016; Ayeni and Oye, 2017). The tallest *S. alatum* plants (71.35 cm) recorded at 2 t ha^{-1} poultry manure application (Table 3.9) were shorter than the *S. indicum* plants (73.41 cm) exposed to poultry manure recorded in Nigeria (Alege et al., 2013).

Manure performance on the plant height varied significantly between seasons before shoot removal (Table 3.9) but did not differ significantly after shoot removal (Table 3.10). Plants that were subjected to 3 t ha^{-1} of goat manure were the tallest before and after shoot removal compared with plants that were exposed to poultry manure. Whereas lower rates of manure application (≤2 t ha^{-1}) had significantly similar heights, which were higher than control plants.

Plant elongation is dependent on the availability of growth nutrients such as nitrogen, which is the most important limiting factor in plant growth and development (Tovihoudji et al., 2015; Fonge et al., 2016). This relationship between plant height and nitrogen intake was reported on *Amaranthus dubius* (Ahmad et al., 2019). Nitrogen deficiency results in stunted plants (Tovihoudji et al., 2015) this was evident with plants that received no manure in the present study.

b. Stem diameter

There were no significant variations in stem thickness between seasons (Table 3.6). Contrary, a similar study reported seasonal variations in the stem diameter of *S. indicum* cultivated in Nsukka, Nigeria (Ogbonna and Umar-Shaba 2012). The stem thickness increased with the increase in manure application rates (Table 3.8). This increase in stem thickness with increasing poultry manure application rates was also reported in *S. indicum* (Ogbonna and Umar-Shaba, 2012). Furthermore, increased stem girth has been reported in Nigeria when poultry and cow manure were applied at 4 t h^{-1} to *S. indicum* (Alege et al., 2013). Higher levels >5 t h^{-1} of cow and poultry manure application do not affect the stem diameter of *S. indicum* (Akande et al., 2011; Magalhães et al., 2017).

Similar studies on common wild leafy vegetables show that there was an increase in stem thickness when organic manure was applied. These wild leafy vegetables include *Amaranthus* (Mhlontlo et al., 2007), *Amaranthus dubius* L. (Ahmad et al., 2019), *Amaranthus hydridus* (Ekwealor et al., 2020), *Corchorus olitorius* L. (Tovihoudji et al., 2015; Mavengahama et al., 2016) and *Solanum nigrum* L. (Bvenura and Afolayan, 2013).

An increase in stem thickness is considered secondary plant growth caused by the lateral meristems cell division and expansion (Spicer and Groover, 2010). Organic manure is capable of recycling essential nutrient biomass of less productive agricultural soils, which improves the plant meristematic activities for enhanced growth and crop quality (Adediran et al., 2015). This suggests that the application of poultry and goat manure provided a better source of nutrients, which resulted in a significant increase in stem diameter.

c. Number of branches and leaves

The significantly higher branch number was obtained in season two at 60 DAS (Table 3.6). At 60 DASR, a greater number of sub-branches was obtained in season one (Table 3.7). The treated *S. alatum* plants were higher in the number of branches compared to control plants at 60 DAS, but there were no significant differences in the source and rate of application of poultry and goat manure. A similar increase in branch number was reported in S. *indicum* with the application of poultry manure (Ndor and Nasir, 2019). This was also noted in *Corchorus olitorius* with chicken manure application (Mathowa et al., 2014). However, results reported on *C. olitorius* where the number of branches was not affected by the application of poultry manure were contrary to the current findings (Law-Ogbomo and Osaigbovo, 2016).

Plant shoot multiplication (branch formation) is one of the harvestable yields determining factors for leafy vegetable plants regarding the fact that the increase in the branch number subsequently increased harvestable positions. The number of branches can be increased with added nitrogen, this was reported in *C. olitorius* (Mavengahama et al., 2015). Organic manure provides a wide range of essential nutrients activating the microbial properties, which release phytohormones for plant cell multiplication and physiological improvements (Mathowa et al., 2014; Adediran et al., 2015; Fonge et al., 2016). At 60 DASR, the number of main branches was significantly higher at 3 t ha^{-1} of goat manure application when compared with control but did not differ significantly with the rest of manure treatment rates. The number of sub-branches at 60 DASR was also increased at goat manure application-level ≤2 t ha^{-1}. These results were not in agreement with those recorded in *S. indicum* where there was no significant increase in the number of secondary branches with animal manure application (Magalhães et al., 2017).

Sesamum alatum produced numerous leaves in the second planting season at 60 DAS and the first season at 60 DASR (Table 3.5 and 3.6). This increase in leaf number was directly affected by the increase in branch number in the present study. Contrary, a study that was conducted to evaluate the effect of poultry manure on *S. indicum* growth and yield performances showed that the increased number of branches had no significant effect on the leaf number (Ogbonna and Umar-Shaba, 2012). The leaf number of *Sesamum alatum* plants responded positively in poultry and goat manure when compared to control plants (Table 3.7 and 3.8). A similar study on *Abelmoschus esculentus* reported a greater number of leaves produced were grown under poultry and goat manure (Chinatu and Okoronkwo, 2016).

Animal manure increased leaf number of *S. indicum* (Alege et al., 2013; Usman et al., 2016), *A. esculentus* (Tiamiyu et al., 2012), *Amaranthus cruentus* (Akparobi, 2009), *A. dubius* L. (Ahmad et al., 2019); *Amaranthus* (Mhlontlo et al., 2007), *Corchorus olitorius* L. (Tovihoudji et al., 2015; Musa et al., 2020) and *Solanum nigrum* L. (Bvenura and Afolayan, 2013). At 60 DAS, there was a steady increase in leaf number for both manure treatments with the highest number of leaves produced with goat manure at 3 t ha^{-1}. After shoot removal, plants that were exposed to 2 t ha^{-1} of goat manure amended soils produced the highest leaf number. The increase in leaf number of *S.*

alatum with the increase in the rate of manure application may be attributed to the increasing supplies of plant growth nutrients, improved soil organic carbon, stable pH levels, and cation exchange capacity (CEC) from both manures.

Organic manure has been used in crop production not only for its ability to increase harvestable yields but for its proven capability to rehabilitate degrading soils for improved vegetative growth in plants (Tiamiyu et al., 2012). At 60 DAS, the results on the seasonal performance of *S. alatum* under poultry and goat manure showed no significant increase in leaf number in season one but in season two (Table 3.9). At 60 DASR, a greater number of leaves was produced in the second season compared to the first season, but there were no significant differences between manure treatment rates and control (Table 3.10).

e. Leaf size

The leaf size varied significantly between seasons with the biggest leaves obtained in the second season (Table 3.5). This increased leaf area may be attributed to the high rainfall received during the second season planting months compared with the first season (Table 3.4). The reported high P, K, exchangeable cations (Ca, Zn, Mn, and Cu), CEC, and clay contents in sandy-loam soil and manure from the second season may have also caused the increase in leaf size of *S. alatum* (Table 3.3). An increase in soil clay content has been correlated with an increase in microbial properties, and nitrogen mineralisation (Mkhabela, 2006). The application of poultry and goat manure significantly increased measured leaf parameters (length, width, and area) (Table 3.7).

Sesamum indicum produced the biggest leaves under poultry manure subjection compared to plants that received no manure treatment (Haruna, 2011; Alege et al., 2013). Poultry manure application on *Abelmoschus esculentus* significantly increased the leaf area (Khandaker et al., 2017). The increase in leaf size by the application of organic manure has been reported in many other similar agro-morphological studies on *Corchorus olitorius* (Tovihoudji et al., 2015; Musa et al., 2020), *Amaranthus cruentus,* and *Vernonia hymenoepis* A. Rich (Fonge et al., 2016). *A. hybridus* (Ekwealor et al., 2020), *A. dubius* L. (Ahmad et al., 2019), and *Solanum nigrum* L. (Bvenura and Afolayan, 2013). However, there were no significant differences in the source and rate of manure for all leaf parameters (Table 3.7). Several plant growth parameters are not easy to quantify without measuring the leaf area at different stages of plant growth (Khandaker et al., 2017). Leaf size affects many basic plant metabolic processes, which perform basic activities in the initiation of secondary plant growth.

f. Shoot mass

The shoot mass varied significantly between seasons (Table 3.6). Manure-treated plants produced significantly higher shoot fresh mass when compared with control plants with the highest recorded from 3 t ha^{-1} of poultry, 2 and 3 t ha^{-1} of goat manure, other rates of application were not significantly different from the control (Table 3.7). The shoot fresh mass of *Amaranthus* was reported to increase significantly when exposure to 2.5, 5 and 10 t ha^{-1} of animal manure (Mhlontlo et al., 2007). This increase in the shoot fresh mass was also reported in *Corchorus olitorius* at higher rates of poultry manure (Tovihoudji et al., 2015). The application of animal manures improved the leaf and stem fresh mass of *A. hybridus* and *Cleome gynandra* (Seeiso and Materechera, 2014).

The seasonal shoot dry mass did not differ significantly (Table 3.6). The application of manure did not enhance shoot dry mass contents (Table 3.7). This suggest insufficiency in the rates of manure application on *S. alatum* for improved shoot dry mass. Similarly, the leaf and stem dry mass of *Amaranthus hybridus* and *Cleome gynandra* had no significant increase when goat and poultry manures were applied (Seeiso and Materechera, 2014). When organic manure was applied to *C. olitorius* no significant increase in dry mass was noted (Tovihoudji et al., 2015). These findings are contrary to the results obtained with *Amaranthus* species, which showed a significant increase in shoot dry mass when animal manure was applied (Maerere et al., 2001; Mhlontlo et al., 2007; Akparobi, 2009). Shoot dry mass is an accurate and acceptable measure of plant biomass, which provide estimates for plant's harvest (Golzarian et al., 2011).

g. Shoot moisture

The first planting season recorded the highest shoot moisture content compared with the second planting season (Table 3.5). This increase in shoot moisture may be linked to high rainfalls that occurred in October in the first season (Table 3.4). Plants shoot tips were removal 60 DAS, which was at end of October of each planting period. Hence the high moisture content was recorded throughout the study. There were insignificant variations in the shoot moisture content of poultry and goat manure treated plants compared with the control (Table 3.7). Although organic manure increases the soil moisture content (Cho et al., 2017), it was probably not transferred to *Sesamum alatum* shoots. The shoot moisture of *Solanum nigrum* was reported to increase significantly under the goat manure at 8.13 t ha^{-1} (Bvenura and Afolayan, 2014). Animal manures (poultry and cow) increased the leaf and stem moisture contents of *Corchorus olitorius* at 10 t ha^{-1} (Makinde et al., 2011).

3.6.3 Effect of poultry and goat manure on reproductive traits of *S. alatum*

The results showed that the pod number and pod diameter of *S. alatum* were significantly variable between seasons, but the number of seeds per pod, pod length, and 1000 seed mass did not differ significantly between growing seasons (Table 3.11). The application of poultry and goat manure produced a significantly higher number of pods per plant, number of seeds per pod, pod length, and diameter (Table 3.12). Goat manure had the greatest improvement in reproductive traits compared with lower rates (≤2 t ha^{-1}) of poultry manure (Table 3.12). Similar studies on yield in response to manure application recorded an increase in pod number of *S. indicum* (Haruna, 2011; Eifediyi et al., 2018) and *C. olitorius* (Tovihoudji et al., 2015). Organic manure contains essential reproduction nutrients, which are basic requirements for optimised yield, hence a greater effect of reproductive traits was obtained with manure in the present study (Khandaker et al., 2017). This can also be linked to the increase of leaf area in *S. alatum*. Leaf size determines plant photo assimilation and is a significant factor in defining crop yield (Weraduwage et al., 2015). The bigger the leaves the greater the light interception for photosynthetic activities to drive energy for numerous and bigger pods.

Crop reproductive traits are dependent on soil fertility especially the availability of phosphorus and potassium (Eifediyi et al., 2018). Reproductive traits have been reported to be depressed in high levels of soil nutrient availability (Haruna and Aliyu, 2011 c) but enhanced in soils with a low nutrient status (Haruna and Aliyu, 2011 c; Haruna and Abimiku, 2012). Organic manure provides nitrogen to the soil in a slow and gradual process, which results in excess nitrogen that has been reported to reduce the number of pods per plant (Eifediyi et al., 2018). The increase in reproductive parameters of *S. alatum* suggests that there was a decrease in nutrients of the manure amended soils, which may have been invested in the promotion of the vegetative growth traits. This was also reported on *Abelmoschus esculentus* when organic manure was applied (Tiamiyu et al., 2012).

a. Number of days to flower and pod formation

Sesamum alatum produced the first flower and pod from plants that received manure treatment (Figure 3.3 and 3.4). The number of days it took manure-treated plants to flower did not vary with source and rate of application in season one (Figure 3.3 a), but there were prominent variations in days to flowering at season two (Figure 3.3 b). The fewer days to reproduction was evident in *S. indicum* where a significant decrease in the number of days to flowering was recorded when animal manure was used (Nurhayati et al., 2016). Early flowering was induced with poultry manure treated *Corchorus olitorius* plants followed by goat manure in both cropping seasons, which was in accordance with the current results (Ayeni and Oye, 2017).

b. Number of pods

The pod number depicted a significant variation between seasons, with the highest number of pods recorded in the second season (Table 3.8). This seasonal variation in pod number may have been attributed to the high rainfalls received in December of the second cropping season. A greater pod number of *S. indicum* was recorded with the increase in precipitation (Eifediyi et al., 2018). These findings are in support of the slight seasonal variation in the number of pods reported in *Abeimoschus esculentus* (Chinatu and Okoronkwo, 2016). The application of manure to *S. alatum* plants produced higher pod number (Table 3.8). Poultry manure enhanced pod number in *S.*

indicum (Alege et al., 2013; Usman et al., 2016; Eifediyi et al., 2018; Ndor and Nasir, 2019).

Similarly, animal manure application increased pod number in *S. indicum* (Haruna and Abimiku, 2012). Goat and poultry manure increased the number of pods in *A. esculentus* (Chinatu and Okoronkwo, 2016). There were no significant differences between all rates of poultry manure, 1 t ha^{-1} goat manure, and control in season one (Table 3.8). Poultry manure lower (5–10 t ha^{-1}) application rates had no significant effect on the number of *S. indicum* pods in season two (Eifediyi et al., 2018).

c. Pod length and diameter

Pod length showed an insignificant increase between seasons, but pod diameter was significantly higher in season one compared with season two (Table 3.8). The increased pod thickness may be attributed to the low soil and manure nutrient contents in season one compared with season two (Table 3.3). High soil nutrients as a result of manure application have been reported to have reduced the *S. indicum* plant reproductive performance (Haruna and Aliyu, 2011c).

Poultry and goat manure significantly increased the pod length and diameter of *S. alatum* (Table 3.8). Similar trends were reported on *A. esculentus* plants exposed to poultry, goat, and cow manure (Chinatu and Okoronkwo, 2016). This contradicts the non-significant increase in pod length and diameter reported in *S. indicum* plants subjected to poultry manure (Alege et al., 2013). Furthermore, no significant increase was recorded in pod length of *Abelmoschus esculentus* due to the effect of organic manure applied (Tiamiyu et al., 2012).

Goat manure-treated plants produced more elongated and wider pods compared with plants that received poultry and no manure treatments (Table 3.8). This was not in accordance with longer *A. esculentus* pods obtained with poultry manure followed by goat manure (Chinatu and Okoronkwo, 2016). The pod thickness of control plants did not differ significantly from plants that received poultry manure (≤2 t h^{-1}) (Table 3.12).

d. Number of Seeds per pod

The number of seeds per pod did not vary significantly between seasons (Table 3.8). There was a significant increase in seed number for manure-treated plants, except plants that received 1 t h^{-1} of poultry manure when compared with control plants (Table 3.8). Seed yield increments with applied animal manure on *S. indicum* has been reported in many other similar studies conducted in different regions and times (Haruna, 2011 a and b; Haruna and Aliyu, 2011; Haruna and Abimiku, 2012; Eifediyi et al., 2018; Ndor and Nasir, 2019; Lokhande et al., 2020). This increase in seed yield was also reported in *Abelmoschus esculentus* (Chinatu and Okoronkwo, 2016) and *Corchorus olitorius* (Tovihoudji et al., 2015). The increase in soil nutrients is known to be detrimental to enhanced reproductive traits performance of the plants (Alege et al., 2013) but not in the current study.

e. Seed Mass

The 1000 seed mass had insignificant variations between seasons (Table 3.8). Untreated plants produced heavier seeds but were only significantly higher than the seed mass of plants treated with 3 t h^{-1} of goat manure (Table 3.8). Poultry manure had an insignificant effect on the seed mass of *S. indicum* plants (Haruna and Abimiku, 2012; Alege et al., 2013). The insignificant effect on the seed mass was also noted in *S. indicum* subjected to animal manure (Magalhães et al., 2017).

3.7 Conclusion

The soil and manure used had low organic carbon, N, P, Ca, Mg, and Cu content, which are often linked to produce no and a low agro-morphological effect in plants. Goat manure had high amounts of K and Zn whereas poultry had high quantities of Mn and Zn. Most measured vegetative and reproductive traits were affected by the reported rainfall and a slight nutrient increase in manure used in the second planting season. The increase in plant height, number of branches and leaves, leaf size, shoot fresh and dry mass, and yield recorded in *Sesamum alatum* plants that were treated with manure over control suggests that animal manures such as poultry and goat manure are efficient in the improvement of crop production. Improved plant growth and development require adequate soil essential plant growth nutrients and organic matter. The application of goat manure at rates ≥ 2 t ha^{-1} gave the highest vegetative traits in *S. alatum*. The effect of poultry and goat manure showed an insignificant difference between each other on vegetative traits but there were slight variations in reproductive traits. This suggests that in the absence of goat manure, poultry manure (≥ 2 t ha^{-1}) can be used as an alternative. Chapter four focuses on the effect of poultry and goat manure on the nutrient content of *S. alatum* shoot harvested 60 DAS.

Chapter Four

Effect of poultry and goat manures on the nutrient content of *S. alatum*

Parts of this chapter were submitted for publication as follows: Mbatha, K.C., Mchunu, C.N., Mavengahama, S. and Ntuli, N.R. Effect of poultry and goat manures on the nutrient content of *Sesamum alatum* leafy vegetable in rain-fed systems. *Applied Sciences*. (**Submitted**)

4.1 Introduction

Malnutrition remains a serious problem in rural and semi-urban communities of South Africa and elsewhere (Mavengahama et al., 2015). This is a result of dietary deficiencies in iron, vitamin A and zinc (Oelofse and van Averbeke, 2012; Aworh, 2018). Economically needy nations continue to be dominated by this so-called 'hidden hunger' (Oelofse and van Averbeke, 2012; Ejoh et al., 2021 a and b). However, many individual communities of these nations participate in the gathering and cultivation of wild vegetables for sustenance and consumption to eradicate food insecurity and poverty (Lewu and Mavengahama, 2011). These wild leafy vegetables (WLVs) especially the neglected and underutilised species are readily available and cheap and provide nutrient diversity and food security to local farmers' diets (Tovihoudji et al., 2015; Ejoh et al. 2021a and b). The role played by WLVs is undisputed in the combat of 'hidden hunger' and malnutrition eradication but still needs agronomic interventions (Ntuli, 2019). Micronutrients contents of uncultivated WLVs frequently compare well with commercially cultivated and commonly consumed WLVs (Ejoh et al. 2021b).

The 400 g daily intake of fruits and vegetables recommended by the World Health Organisation presents a challenge to many rural and semi-urban communities' food security thresholds in the world (Aworh, 2017). This is due to a decline in the consumption of vegetables, which enhances nutritional deficiency disorders and diseases in many rural communities in African (Odhav et al., 2007). The increasing disinterest amongst the youth in traditional foods is recognised as a factor contributing to the neglect. Many countries have recently shown a renewed research interest to promote the cultivation of WLVs to increase the micronutrient of rural people's food baskets (Ejoh et al., 2021 a and b).

Sesamum alatum (also known as winged-seed sesame) is a scarcely known wild leafy vegetable (WLV) of great importance in KwaZulu-Natal, South Africa (Ntuli et al., 2019) and other parts of the globe (Bedigian, 2004 and 2018). It is an erect, year-round, mucilaginous herbaceous plant (Mariod et al., 2017). The plant has high nutraceutical properties and the potential of contributing a significant amount to the recommended 400 g daily intake (Sarath Babu et al., 2016). *Sesamum alatum* comprises an excellent amount of proteins, carbohydrates, dietary fibre, fats, Calcium, N, P, K, Mg, and other trace elements such as Cu, Fe, Mn, Na, and Zn, which compare well with *Amaranthus hydridus* (Ntuli, 2019). It also contains essential antioxidants, which can be linked to its use as an ayurvedic medicine to cure various forms of diseases such as, diarrhoea, intestinal disorders, (Mariod et al., 2017), and diabetes (Rajkiran et al., 2011; Sundarakumar and Karmegam, 2018). It is also used as an aphrodisiac by humans and for livestock fertility promotion (Mariod et al., 2017).

Due to high costs and less accessibility of inorganic manures, as well as farming choices some small-scale farmers rely heavily on organic manures (Seeiso and Materechera, 2014; Usman et al., 2016; Ayinla et al., 2018), which includes animal manures, compost, and green manures (Ekwealor et al., 2020). Organic manures are essential waste products in the improvement of plant nutrients (Loh et al., 2005; Ayinla et al. 2018; Adekiya et al., 2020). They improve plant root rizoster conditions, which enhance the assimilation of nutrients from the soil (Mofunanya et al., 2014).

Applications of poultry manure (2.5–6 t ha^{-1}) caused an increase in the Ca, Mg (Akande et al., 2011), ash, fats, N, P, and proteins contents of *S. indicum* leaves (Anguria et al., 2017). The ash, moisture content, proteins, carbohydrates, fibre, fat, N, P, and K in *C. olitorious* leaves increased when poultry manure was applied at 1 and 2 t ha^{-1} (Ayinla et al., 2018). The increase in the ash, fat, and protein content was also noted in *Amaranthus caudatus*, *A. cruentus* (Kahu, 2017), and *A. hybridus* (Adedeji et al., 2019) when poultry manure was applied. Further, the proximate and mineral contents of *A. cruentus*, *A*. *hydridus*, *A. deflexus,* and *A. spinosus* increased with the application of 0.03 t ha^{-1} of poultry manure (Oyedeji et al., 2014). Poultry manure application produced low moisture content, which is advantageous in the extension of plant shelf-life (Kahu, 2017). Goat manure applied at rates between 2.5–13 t ha^{-1} increased Ca, Mg, N, P, and K content in *Capsicum annuum* leaves (Awodun et al., 2007). The increase in the P content of *Cleome gynandra* was increased with the application of 8 t ha^{-1} goat manure compared with Ca, Cu, Fe, K, Mg, Mn, Na, and Zn content increments (Sowunmi, 2015).

Agronomic interventions on WLVs such as *S. alatum* can be used as a developmental strategy in the world problem of low food production and malnutrition. 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. *Sesamum alatum* is one of the wild-collected leafy vegetables with no agronomic studies on its improvements under different soil fertilities using animal manure. Therefore, the objective of this study was to examine the effect of poultry and goat manures on the nutrient content of *S. alatum*.

4.2 Materials and Methods

The study site and experimental design of this study are explained in chapter three. At 30 days after planting a length of the 4-8 cm long tender shoot tips was harvested from each plant across all treatments and concentrations for nutrients analyses. Proximate and elemental analyses were conducted according to the Association of Official Analytical Chemists (AOAC) (1990) and Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) methods (Manson and Roberts, 2000). Mineral analysis of shoots was conducted at the Department of Agriculture and Rural Development, Soil Fertility and Analytical Services section in KwaZulu-Natal (Cedara).

4.2.1 Proximate analysis

The moisture content, protein, acid detergent fibre, neutral detergent fibre and fat of samples from each treatment was analysed in triplets (Alege et al., 2013). Harvested shoots were wasted with distilled water to remove soil and organisms that might interfere with the accuracy of measurements and then dried properly before grinding them to powder for analysis.

Moisture: The moisture content was determined by drying the dish and lid and then weighing 3 g of sample. The sample was uniformly spread in the dish and lidded. The preparation was then placed in a vacuum oven at 65 °C for 3 hours. The lidded dish was then transferred to a desiccator for cooling. After cooling the dish with the sample was dried and reweighed. The results of the process were expressed in percentages obtained using the formula:

$$Moisture\ content\ \% = \frac{Weight\ before\ dryimg - Weight\ after\ dryimg}{Weight\ before\ drying} \times 100$$

Crude proteins: Protein extraction and analysis were done according to Kaburi (2015). 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 H_2SO_4 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 achieved. 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. Roughly 10 mL of the digest 100 mL solution was pipetted into a distillation flask with 90ml of distilled water. Twenty millimetres of (40%) NaOH were pipetted into the distillation flask. A 250 mL conical flask with 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 0.1N HCl until a pink colour appeared. The titrated volume was then minus from the original sample titrated volume. Values obtained from the above process were used to calculate the N content percentage of the sample using the formula:

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

The crude protein percentage was calculated by multiplying % N with ×6.25 factor.

Crude fibre (Acid Detergent Fibre and Neutral Detergent Fibre): Crude fibre was estimated by (1.25%) H_2SO_4 and (1.25%) NaOH solutions. A 2 g of ground material was initially boiled at 35–38 °C and finally at 52 °C with ether or petroleum ether to remove fat. Ether extract residue was then introduced into a digestion flask along with a 200 mL boiling H_2O_4 solution. An anti-foaming agent was added and be connected to the flask immediately with a condenser and heated for 30 minutes. After that time the digestion flask was removed and filtered immediately for its content using a linen cloth and then washed using boiling water till the acid is 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 minutes. After 30 minutes the flask was removed, and the precipitate content was filtered with gooch crucible and then wash it 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 minutes in a furnace at 550 °C until the carbonaceous matter was consumed. It was cooled again in a desiccator and taken the final weight measurements. The following formula was used to calculate crude fibre as the loss in weight:

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

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 done by placing the bottle and lid in the incubator at 105 °C for 12 hours. About 100 g of the sample will be 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 hours at a heat rate of 150 drops/min. The solvent was completely evaporated using a vacuum condenser, incubated at 80–90 °C until the bottle becomes dry. Transfer the lid bottle to the desiccator for cooling and reweigh the dried content of the bottle. The results were expressed in percentages, using the formula:

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

4.2.2 Mineral analysis

The mineral elements analysis of Ca, Cu, Fe, K, Mg, Mn, Na, P, and Zn in the samples were quantified in triplicates using ICP–OES (Manson and Roberts, 2000). The plant material samples were analysed using the Batch-handling procedure as described by

Manson and Roberts (2000). 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 be 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.

4.3 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 (SAS Institute Inc, 2011, Version 9.4). Tukey's Studentized Range test (HSD) was used to compare treatment means at $P < 0.05$.

4.4 Results

4.4.1 Macronutrients

a. Acid Detergent Fibre and Neutral Detergent Fibre

The acid detergent fibre was higher in the second season than the first season, but a similar neutral detergent fibre content was recorded in both seasons (Table 4.1). *Sesamum alatum* control plants had more acid detergent fibre content compared with 2 t ha^{-1} of poultry manure-treated plants (Table 4.2). Again, the variation in manure types and quantities did not affect the acid detergent fibre concentration in *S. alatum* (Table 4.2). The neutral detergent fibre was higher in plants that were treated with goat manure at rates ≥ 2 t ha^{-1} than untreated plants (Table 4.2). The highest acid detergent fibre content was recorded with the control in the first season and 3 t ha^{-1} of poultry and goat manure in the second season. However, the highest acid detergent fibre contents were compared with all other application rates except rates ≥2 t ha^{-1} of poultry manure (Table 4.3). The highest neutral detergent fibre contents obtained with no manure application in season one was comparable to the neutral detergent fibre contents achieved with 1 t ha–1 of poultry manure and all goat manure rates, but in season two no variations in the neutral detergent fibre content were noted between the manure rates and control (Table 4.3).

Table 4.1. Response of nutrient content to seasonal variation in poultry and goat manure treated *Sesamum alatum* plants.

Nutrients	Season		Significance
	One	Two	
Macronutrients (%)			
Acid Detergent Fibre	20.34 [b]	22.51 [a]	***
Neutral Detergent Fibre	29.39	30.11	NS
Calcium	0.91 [a]	0.68 [b]	***
Magnesium	0.54 [a]	0.38 [b]	***
Potassium	2.96 [a]	2.00 [b]	***
K/Ca+Mg	0.80 [a]	0.76 [b]	***
Fat	3.98	3.39	NS
Phosphorus	0.29 [a]	0.25 [b]	**
Protein	36.76 [a]	34.12 [b]	***
Micronutrients (ppm)			
Copper	11.48 [a]	7.52 [b]	***
Iron	399.00 [a]	198.33 [b]	***
Manganese	64.48 [a]	46.62 [b]	***
Sodium	1500.00 [a]	900.00 [b]	***
Zinc	49.67 [a]	40.48 [b]	***

K/Ca+Mg, potassium/calcium + magnesium; Superscripts within a column indicate significant differences in Tukey's Studentized Range (HSD) ($P<0.05$). Significance level: NS, not significant; ** $P < 0.01$; *** $P < 0.001$.

Table 4.2. Effect of poultry and goat manure on *S. alatum* nutrient content.

Nutrients	**Manure (t ha^{-1})**							Significance
	Control	Poultry			Goat			
	0	1	2	3	1	2	3	
Macronutrients (%)								
Acid Detergent Fibre	22.57 a	20.96 ab	20.07 b	21.11 ab	21.68 ab	21.20 ab	22.37 ab	*
Neutral Detergent Fibre	30.75 a	29.61 ab	27.50 b	28.32 ab	29.86 ab	30.84 a	31.38 a	**
Calcium	0.35 c	1.01 a	0.72 b	0.67 b	1.08 a	0.70 b	1.06 a	***
Magnesium	0.20 e	0.58 abc	0.44 bcd	0.36 ed	0.59 ab	0.42 cd	0.64 a	***
Potassium	1.06 d	3.00 ab	2.65 abc	1.96 c	3.28 a	2.23 bc	3.16 a	***
K/Ca+Mg	0.80 ab	0.78 bc	0.76 c	0.77 bc	0.82 a	0.80 ab	0.77 bc	***
Fat	2.88 ab	3.23 ab	2.03 b	3.56 ab	4.66 a	4.78 a	4.65 a	**
Phosphorus	0.08 d	0.33 abc	0.27 abc	0.25 bc	0.37 a	0.22 c	0.35 ab	***
Protein	36.09 a	33.39 c	36.77 a	35.91 a	33.63 bc	36.69 a	35.61 ab	***
Micronutrients (ppm)								
Copper	5.00 c	11.00 ab	8.67 bc	8.50 bc	13.67 a	5.67 c	14.00 a	***
Iron	253.00 dc	307.67 abc	269.17 bcd	227.33 d	352.50 a	349.00 a	332.00 ab	***
Manganese	38.00 d	60.67 b	52.00 bc	43.00 cd	91.50 a	48.17 bcd	55.50 bc	***
Sodium	700.00 d	1300.00 bc	1100.00 c	1100.00 c	1600.00 a	1200.00 bc	1500.00 ab	***
Zinc	29.00 d	49.33 ab	45.83 abc	42.83 bc	57.33 a	36.00 cd	55.17 ab	***

K/Ca+Mg, potassium/calcium + magnesium. Superscripts within a row indicate significant differences in Tukey's Studentized Range (HSD) ($P<0.05$).

Significance level: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Table 4.3. Interaction between season and manure on *Sesamum alatum* nutrient content.

Season x 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; MC, Moisture content; NDF, Neutral Detergent Fibre; NS, not significant; S1, season one; S2, season two. Means with different superscripts within a column indicate significant differences in Tukey's Studentized Range (HSD) ($P<0.05$). Significance level: NS, not significant; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

b. Calcium, magnesium, and potassium

Calcium, magnesium, and potassium contents were higher in the first than in the second season (Table 4.1). Generally, the calcium, magnesium, and potassium contents were higher in plants from soils treated with poultry and goat manure than in the control (Table 4.2). 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. Potassium content recorded 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 4.2).

The interaction between seasons and manures shows that 3 t ha^{-1} goat manure-treated plants had a higher calcium content compared with the control in both seasons and poultry manure rates that were ≥ 2 t ha^{-1} as well as 2 t ha^{-1} of goat manure in season two (Table 4.3). Similarly, magnesium content was higher in plants that received 3 t ha^{-1} of goat manure but was only significantly different with rates ≥ 2 t ha^{-1} of poultry manure, 2 t ha^{-1} of goat manure in the second season and control of each season (Table 4.3). The potassium content was higher with the application of 2 t ha^{-1} of poultry manure than control in season one. No variations were noted between type and rate of manure application in *Sesamum alatum* potassium content (Table 4.3). In season two, the potassium content obtained with poultry manure (≥2 t ha^{-1}) and 2 t ha^{-1} of goat manure was comparable with the control. Further, lower (<2 t ha^{-1}) rate of poultry manure was similar to 1 and 3 t ha^{-1} of goat manure in season two (Table 4.3).

Plants that were grown in season one had higher potassium/calcium + magnesium content compared with the second season (Table 4.1). The highest K/Ca + Mg content was recorded in 1 t ha^{-1} of goat manure-treated plants (Table 4.2). 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 3 1 t ha^{-1} (Table 4.2). 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 comparable with 3 t ha^{-1} of poultry manure and 2 t ha^{-1} of goat manure in the same season (Table 4.3).

c. Fat

A similar fat percentage was obtained in both seasons, with the values of (3.98 and 3.39%), respectively (Table 4.1). The greatest fat content was recorded in goat manure-treated plants (Table 4.2). 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, (2.58 and 4.79%) in the second season (Table 4.3). In season one, higher (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.

d. Phosphorus

Plants grown in the first season had a higher phosphorus content than plants cultivated in the second season (Table 4.1). Poultry and goat manure increased the phosphorus content on *Sesamum alatum* plants when compared with the control (Table 4.2). The phosphorus content of plants that were exposed to 1 t ha^{-1} of goat manure was higher than plants that received 2 t ha^{-1} of goat manure and 3 t ha^{-1} of goat manure but similar to all other manure rates (Table 4.2). 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 did not affect the phosphorus content in the second season. The highest (0.43%) P content was recorded with 3 t ha^{-1} of poultry and goat manure in seasons one and two, respectively (Table 4.3).

e. Protein

Again, plants grown in the first season had higher protein content than the second season (Table 4.1). The protein amount recorded with 2 t ha^{-1} of poultry and goat manure was the greatest but similar to the protein contents achieved with 3 t ha^{-1} of poultry and goat manure as well as no manure treated plants (Table 4.2). The smallest rates of manure application (1 t ha^{-1}) recorded the least protein contents. The type and different rates of manure application show poultry manure to have a higher influence on the improvement of protein content in *S. alatum* compared with 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 comparable with other treatment rates except for some rates of goat manure (1 and 3 t ha^{-1}). The lowest protein content (33.63%) was 1 t ha^{-1} of goat manure in season one. In the second season, the least protein content obtained with 1 t ha^{-1} of goat manure varied from the rest of the experimental treatments, which have similar protein amounts (Table 4.3).

4.4.2 Micronutrients

Higher copper, iron, manganese, sodium, and zinc contents were recorded in *S. alatum* plants during season one compared with season two (Table 4.1). Plants that were exposed to 1 and 3 t ha^{-1} of goat manure amended soils produced the highest copper content but were similar to plants that received 1 t ha^{-1} of poultry manure (Table 4.2). The highest iron was 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 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 with 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 did not affect the copper content (Table 4.3). Interaction between season and manure shows that the application of manure caused an increase in iron season one when compared with control. The highest iron content was recorded in season one with 2 t ha^{-1} of goat manure but was similar to 1 t ha^{-1} of goat manure-treated plants. In season two manure application did not affect the iron content. The highest manganese content was obtained with 1 t ha^{-1} of goat manure in both seasons (Table 4.3). 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 4.3). 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 the lower rate (1 t ha^{-1}) of poultry manure and goat manure rates (≥ 2 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 4.3).

4.5 Discussion

4.5.1 Macronutrients

a. Acid Detergent Fibre and Neutral Detergent Fibre

The acid detergent fibre and neutral detergent fibre contents were not increased with the application of manure (Table 4.2). Similarly, there was an insignificant difference in the fibre percentage of *S. indicum* plants that were grown under poultry manure soil amendments (Alege et al., 2013). To measure the quality and digestibility in feeds ADF and NDF, which make the crude fibre are important parameters aside from protein and leaf to stem ratio (Tucakj et al., 2021), the ability of poultry and goat manure to maintain the fibre content low may increase the digestibility of the plant. The ADF and NDF content produced with manure application was comparable with the control except for 2 t h^{-1} of poultry manure (Table 4.2). *Corchorus olitorius* had a significant increase in fibre content under 1 and 2 t h^{-1} of poultry manure (Ayinla et al., 2018).

b. Calcium, magnesium, and potassium

The higher calcium, magnesium, and potassium contents were obtained in season two (Table 4.1). The general increase in Ca, Mg, and K concentration of *Sesamum alatum* under manure-treated plants compared with control plants (Table 4.2) was probably due to nutrient release from poultry and goat manure (Table 3.3). This contradicts the decrease in Ca and Mg contents reported in *S. indicum* plants subjected to poultry manure (Alege et al., 2013). A similar increase in K concentration was reported in *S. indicum* plants treated with 5 t h^{-1} of poultry manure (Alege et al., 2013). Calcium is an important nutrient for healthy bones, contraction and relaxation of body muscles, and coagulation (Emebu and Anyika, 2011, Sowunmi, 2015). Magnesium is an enzyme co-factor in metabolic processes, protein synthesis, and like Ca, it is also involved in preventing bleeding disorders, as well as preventing degenerative diseases and immunological dysfunction (Mohammed and Sharif, 2011). Potassium also promotes good myosin-actin cycling, increases iron availability in the body while it regulates the pH balance and neurotransmission (Sowunmi, 2015).

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 4.3). A similar interaction was reported in *Abelmoschus esculentus* due to the effect of poultry manure application (Adekiya et al., 2020). Goat manure applied at 2.5–12 t h^{-1} increased the concentration of Ca, Mg, and K in *Capsicum annum* leaves during both planting seasons (Awodun et al., 2007). Again, Ca, Mg, and K contents in *C. gynandra* were found to be higher in goat manure compared with control (Sowunmi, 2015). The same response was also noted in *Amaranthus cruentus* with goat manure-treated plants (Ojeniyi and Adejobi, 2002).

The highest calcium content was recorded in 3 t ha^{-1} of goat manure-treated plants in both seasons and poultry manure (≥ 2 t ha^{-1}) as well as 2 t ha^{-1} of goat manure in season two (Table 4.3). This is due to high levels of calcium content recorded in goat manure in both seasons and poultry manure in the second season (Table 3.3). 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 control of each season. Organic manure has been used in crop production not only for its ability to increase harvestable yields but for its ability to replenish soil nutrients for improved plant quality (Ayinla et al., 2018).

c. Fat

Poultry manure-treated plants had an insignificant difference in fat concentration when compared with the control. A decrease in the fat content with the application of poultry manure was recorded in *S. indicum* (Alege et al., 2013) and *A. esculentus* (Adekiya et al., 2020). Contrarily, an increase in fat was noted in *Corchorus olitorius* treated with 1 and 2 t ha^{-1} of poultry manure (Ayinla et al., 2018). Nitrogen applied at high rates limits fat availability in plants (Adekiya et al., 2020). This plant growth nutrient plays a key role in plant metabolism (Fageria, 2001). The fat content recorded with 1 and 2 t ha^{-1} of poultry manure in the present study (Table 4.2 and 4.3) was greater than the fat content of *C. olitorius* achieved the same manure application rates (Ayinla et al., 2018).

d. Phosphorus

The first planting season recorded the highest phosphorus content compared with the second planting season (Table 4.1). The application of poultry and goat manure increased the P concentration in *S. alatum* plants (Table 4.2). *Corchorus olitorius* phosphorus content was higher under poultry manure compared with control plants (Ayinla et al., 2018). Poultry manure application on *Abelmoschus esculentus* increased the fruit P concentration (Adekiya et al., 2020). The increase in leaf P content was reported in *Capsicum annuum* (Awodun et al., 2007) and *Amaranthus cruentus* (Ojeniyi and Adejobi, 2002) when goat manure was applied. Further, goat manure also increased the P content of *C. gynandra* (Sonwunmi, 2015). The increase in N accessibility to plants leads to increased P absorption by plants (Fageria, 2001).

e. Protein

The protein content showed a significant variation between seasons, with the higher content was recorded in the first season (Table 4.1). There were insignificant differences between manure treatment rates ≥ 2 t h^{-1} and control on *Sesamum alatum* protein content, the highest was recorded with 2 t h^{-1} poultry manure treated plant (Table 4.2). A similar study on *S. indicum* reported no improvements in the protein percentage when 5 t h^{-1} of poultry manure was applied (Alege et al., 2013). The current findings are contrary to the significantly increased protein concentration in *Corchorus olitorius* (Ayinla et al., 2018) and *Abelmoschus esculentus* (Adekiya et al., 2020) treated with poultry manure. The highest protein content (39.89%) recorded with 2 t h^{-1} of poultry manure in season one (Table 4.3) was higher than the protein content recorded with the same manure in *C. olitorius* (Ayinla et al., 2018) and *A. esculentus* (Adekiya et al., 2020). Protein (Adekiya et al., 2020) and phosphorus (Fageria, 2001) are nitrogen-dependent nutrients. The high rainfall received 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 3.4).

4.5.2 Micronutrients

Plants that received 1 and 3 t ha^{-1} of goat manure influenced an increase in the copper content when compared with control (Table 4.2). On the contrary, an insignificant response was reported in the Cu content of *Sesamum indicum* under poultry manure intervention (Alege et al., 2013). Goat manure application to *S. alatum* plants increased iron content whereas rates ≥ 2 t ha^{-1} of poultry manure had no effect when compared with the control (Table 4.2). The application of poultry manure at 5 t ha^{-1} caused an increase in the iron content of *S. indicum* (Alege et al., 2013).

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 4.2). The Mn content in *S. indicum* was increased with poultry manure application at 5 t ha^{-1} (Alege et al., 2013). The manure application on *S. alatum* plants caused an increase in sodium content. This was also true for the zinc content except for plants that received 2 t ha^{-1} of goat manure. The sodium and zinc contents were increased with 1 t ha^{-1} goat manure when compared with the control (Table 4.2). Sodium and zinc concentration in *S. indicum* plants grown under poultry manure soil amendments showed an insignificant difference when compared with control plants (Alege et al., 2013). Goat manure has been found to have increased the Cu, Fe, Mn, Na, and Zn content in *C. gynandra* plants (Sonwunmi, 2015).

4.6 Conclusion

Poultry and goat manure application led to an increase in moisture content, Ca, Mg, K, P, and micronutrients in *Sesamum alatum*. The increase in nutrient concentration in *S. alatum* plants treated with manure over control suggests that poultry and goat manure are useful in the improvement of crop nutrient content. However, acid detergent fibre, neutral detergent fibre and protein content in *S. alatum* do not need manure amendments to show its comparative potential in agronomy and nutrient concentration amongst food plants. Goat manure has more potential of increasing the nutrient content in *S. alatum* than poultry manure. However, poultry manure can also be used as an alternative in the absence of goat manure.

Chapter Five

Conclusions and Recommendations

5.1 Conclusions and Recommendations

Plants grown in season one had the higher shoot moisture content, number of small branches and leaves after shoot removal as well as thicker pods, than in season two. However, in the second season plants were taller, had numerous branches and leaves, with bigger leaf areas, numerous pods, and heavier shoots than in the first season. The consistent high rainfall received in September and October during season two before shoot harvest as opposed to season one may be the direct cause of this seasonal variation. However, after shoot removal, the rainfall variation only caused an increase in plant height but depressed the branch and leaf number as well as pod width. The application of poultry and goat manure increased the chemical properties of the soil. Before shoot removal, the application of manure resulted in taller plants with thicker stems, many branches, leaves, and pods, as well as higher shoot dry mass and elongated pods. The shoot fresh mass was only increased with 3 t h^{-1} of poultry manure and goat manure rates ≥ 2 t ha^{-1}. After shoot removal, the increase in branch and leaf number was achieved with goat manure. Thicker pods were produced with 3 t ha^{-1} poultry manure and any rate of goat manure application in this current study. Whereas the number of seeds per pod was increased with poultry manure application levels ≥ 2 t ha^{-1} and all rates of goat manure. Heavier seeds were obtained in control plants. Results showed that goat manure produced better agro-morphological traits and nutrient contents than poultry manure with very few exceptions. The type and rate of manure application showed no significant difference on most vegetative traits of *S. alatum*. However, goat manure high rates (3 t ha^{-1}) suppressed the seed mass. Low manure concentration (1 t ha^{-1}) is thus the best level to give better vegetative results in *S. alatum*.

The nutrient content in *S. alatum* was improved by the application of poultry and goat manure, although the performance of these manures was not consistent for all nutrients. The application of 2 t ha^{-1} poultry and goat manure increased the moisture content while the calcium and copper concentration were increased with 1 t ha^{-1} of poultry and goat manure as well as 3 t ha^{-1} of goat manure compared to control. The magnesium was increased in rates ≤2 t ha^{-1} poultry manure and all rates of goat manure application whereas all rates of manure applications increase the potassium, phosphorus, and sodium content. Iron content was only increased in goat manure-treated plants. The Mn concentration was increased with rates ≤2 t ha^{-1} of poultry manure, 1 and 3 t ha^{-1} of goat manure. However, zinc was significantly increased with all rates of poultry manure, 1 and 3 t ha^{-1} of goat manure application. Nutrients measured in *S. alatum* plants that received poultry and goat manure had surpassed World Health Organisation daily recommended nutrient intake from the 400 g of fruits and vegetables. The application of 1 t ha^{-1} of goat manure gave the optimum nutrient content improvement in *S. alatum*, thus making it an economic feasible choice for resource poor farmers. Protein content of plants that received manure treatment had an insignificant increase when compared with control plants. The domestication of *S. alatum* needs more similar studies to be carried out under different systems (open and completely closed settings, different types of organic and inorganic manures) with aims at recommending best cultivation systems.

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