

Response of okra to varying soils, fertilizer levels and moisture regimes under greenhouse conditions

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DECLARATION

I, Thabiso Khumalo hereby declare that this dissertation, which I hereby submit for the degree of Master of Science in Agriculture at the University of Mpumalanga Mbombela Campus has not previously been submitted to any other institution. I declare that this is my original work, conducted under the supervision of Professor F. R. Kutu. All other sources of data and information used are appropriately acknowledged.

Student's signature.....

Date.....15/04/2025.....

Supervisor's signature.....

Date.....17/4/2025.....

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DEDICATION

This dissertation is one of my greatest accomplishments. Therefore, I dedicate it to myself, my beloved mother (Mzamo Hermanus) and my sisters (Sindisiwe Lukhele, Tholumusa Khumalo and Samukelisiwe Khumalo) for working tirelessly to shape me to be where I am today. And to my friend Bongiwe Nkosi, for her endless love and support.

ABSTRACT

Okra is an economically important vegetable crop that is widely grown in the tropical and sub-tropical regions. The crop is a valued source of minerals and vitamins that are vital for proper maintenance of human health. Regrettably, there is no record of its commercial production in South Africa leading to frequent scarcity and unavailability in the market. The scarcity problem is further exacerbated by the low yield and soil moisture stress due to poor soil fertility and low rainfall amount, respectively as well as its high level of perishability as a fresh vegetable. A factorial greenhouse experiment was conducted at the University of Mpumalanga farm. Trial consisted of two soil textural types (sandy loamy and clay loamy), two moisture regimes ($>80\%$ FC and $<30\%$ FC) and six fertilizer combinations using different mix ratios of inorganic NPK fertilizer and poultry manure (PM) as treatment factors. The different ratios consist of 100% NPK, 100% PM, 75:25 NPK:PM, 50:50 NPK:PM and 25:75 NPK:PM with an unamended control included as a check. The treatment factors were combined to obtain 24 treatment combinations including the moisture imposition that were each replicated four times. Data collection was at weekly intervals for growth and phenological attributes during the 21 days of moisture treatment imposition. Yield attributes were measured at fruit harvest while mineral quality attributes of harvested fruits were assessed prior to storage and 21 days after storage under room temperature.

Results of the study revealed that the integrated use of 75%PM/25%NPK rate significantly ($p<0.05$) increased okra plant growth and measured yield parameters in moisture stressed and non-stressed in both sandy loamy and clay loamy soils. The highest cumulative number of flowers, fruits, fresh and dry fruit weights as well as fruit length and diameter were recorded in the 75%PM/25%NPK treatment. The report of this study revealed locational difference in yield and growth parameters. Although okra gave the best performance on both soils used in the trial, results from clay loam soil were better than in the soil from UMP farm. The interactive effect of variation in soil textural types and Fertilizer combinations produced significantly highest mean fresh fruit weight (77.02 g/plant), number of flowers (4.56 per plant) and fruits (3.17 per plant), fruit length (39.94 mm) and fruit diameter (81.74 mm) all recorded in clay loam soil under 75:25 mix ratio of PM and NPK fertilizer. Similarly, a significant soil moisture regime and fertilizer interaction produced the highest mean fresh (75.38 g/plant) and dry fruit (6.88 g/plant) weights, number of flowers (4.50 per plant) and fresh fruits (2.81 per plant), and fruit length (38.44 mm) and diameter (80.71 mm) per plant in the non-stressed treatment containing 75:25 PM and NPK fertilizer mix ratio. Application of 75:25 PM and NPK fertilizer

mix ratio under sandy loam soil gave the highest measured quality attributes in the non-stressed treatment. Okra fresh weight and the mineral quality attributes were significantly reduced after 21 days of storage with the higher weight loss recorded in the non-moisture stressed treatment. Soil moisture stress reduced the ability of okra to absorb nutrients, which later affected the mineral quality of the okra fruits. Overall, the integrated use of 75:25 mix ratio of this poultry manure and inorganic NPK fertilizer was more beneficial in increasing growth, fruit yield, and mineral nutrients quality of okra plants. The integrated use of 75:25 PM and NPK represents a plausible soil management strategy for promoting increase and sustainable okra production in low fertility soils and moisture stress condition. Nonetheless, collaboration between farmers and researchers is critical for effective implementation of this important agronomic practice to ensure effectiveness at different agro-ecological zones with variable soil types.

Keywords: Okra, soil moisture, poultry manure, NPK fertilizers, soil texture, drought, crop yield, mineral quality, shelf life,

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CHAPTER 1

Introduction

1.1 Background of the study

Okra (*Abelmoschus esculentus*) also known as ladyfinger due to its shape, is an economically important vegetable crop that is widely grown in the tropical and sub-tropical regions (Afe & Oluleye, 2017). Okra is a multi-purpose commodity with immense health and nutritional benefits, including the different plant parts namely the pods, seeds, leaves and stems. The immature fruits of the plant can be consumed as a vegetable when prepared as a salad, soup and stew (Gemedede et al., 2015). The crop is a source of valued nutrients as well as health benefits; and contains high minerals and vitamins contents that are key for proper maintenance of human health and prevent diseases such cancer and poor eyesight (Afe & Oluleye, 2017). It is an important source of vitamin C, contains less calories and is fat-free (Gemedede et al., 2015). Okra contains approximately 87.7% water, 2.2% protein, 0.3% fats, 7.9% carbohydrates, 1.6% fibre and 0.3% ash (Adewole & Ilesanmi, 2011). These nutrients are responsible for maintaining the rate at which sugar is absorbed from the digestive system, and therefore aid in stabilizing blood sugar levels (Liao et al., 2012). Reports abound on the potential of okra to reduce the chance of kidney problems particularly associated with blood sugar levels through frequent consumption (Gemedede et al., 2015; Meena & Bhati 2016; Santos et al., 2019). Similarly, the consumption of okra prevents and helps against gastrointestinal problems (Gemedede et al., 2014).

The growth and quality of okra is enhanced by adding fertilizers such as manure and NPK fertilizers to the soil. fertilizers can also improve the yield of plants (Naresh et al., 2018). Sharma et al. (2020) found that applying nitrogen (N) aids in chlorophyll formation and the uptake of other nutrients, benefits in the processes of photosynthesis, and ultimately increases the overall crop yield. Similarly, the application of phosphorus (P) and potassium (K) either as organic or inorganic fertilizer, not only aids in early root formation and stimulates blooming and seed formation and increase the tolerance of the crop to disorders and insects attack, but also increases the yield and quality of the crop (Adewole & Ilesanmi, 2011). However, inorganic fertilizers have a faster rate of nutrient release to plants than organic fertilizers due to higher nutrient solubility that makes the former more preferred (Attarde et al., 2012). Nevertheless, the use of organic manure has been reported to enhance yielding and nutritional status of the crop (Ansari & Sukhraj, 2010).

The ability of soil to preserve water for plant use influences crop production depending on the amount of moisture that can be preserved and for how long (Tang et al., 2019). According to Courtwright & Findlay (2011), loamy soil has moderate water holding capacity and it is known as an excellent soil type for crop production, owing to its ability to adequately supply crops with water and reduce the chances of flooding. Conversely, clay soil has high water holding capacity that can potentially lead to flooding, death of crops and loss of soil microbes (Tang et al., 2019) whereas sandy soils possess poor nutrient availability and poor water holding capacity (Gao et al., 2018). According to Wang et al. (2019), inhibition of aerobic respiration during waterlogging limits energy metabolism and restricts growth and a wide range of developmental processes, from seed germination to vegetative growth and further reproductive growth. Similarly, plant development processes such as photosynthesis and respiration shut down when there is no available moisture, and plants fail to create glucose to support life processes within the plant, which may result to permanent wilting (Riyazuddin et al., 2022).

1.2 Problem Statement

Notwithstanding the documentary evidence of the nutritional and health benefits of okra, record of commercial production of this important crop in South Africa is scarce and often confined to small-scale or subsistence production leading to frequent shortage in the market. The situation is made worse by low soil fertility, which further impacts on the growth and performance of crops. Although the use of fertilizers and other agrochemicals to promote increased crop production is widely advocated, inappropriate use of these agricultural inputs have been reported to exert undesirable consequences on crop quality, human health and environment (Narkhede et al., 2011; Gemedede et al., 2015). While the use of manure to address soil fertility constraint is considered environmentally friendly, its nutrients release is slow to satisfy crop demand while excessive inorganic NPK fertilizer application have been reported to create harmful effect on growing plants and possibly cause detrimental effect on the environment through the loss of unabsorbed nutrients in surface runoff (Han et al., 2016; Meena & Bhati, 2016).

Furthermore, the increase in climate variable extremes attributed to climate change have posed critical challenges such as reduced production. Climate variability leads to an introduction of new pests in the agricultural production for the past two decades. Which has resulted from frequent drought and heat waves occurrence arising from reduced precipitation and high temperatures (Lone et al., 2017). Climate variability have resulted to reduced crop yield and

quality, food insecurity and increased hunger among vulnerable groups (Deveci & Celik, 2016). Hence, the exposure of okra producers who are mostly small-scale farmers to high risk of low crop yield, poor quality or complete crop failure due to sole reliance on rainfed crop production is exacerbated by limited to lack of access to irrigation facilities (Riyazuddin et al., 2022). Inadequate knowledge on the water requirement under different soil types required to optimize crop production often leads to underwater utilization and wastage due to over irrigation (Abd El-Kader et al., 2010).

1.3 Justification

Okra as a mineral and nutrients-rich vegetable crop that has huge potential to play major roles in addressing food and nutrition security as well as reducing malnutrition (Singh et al., 2014; Benchasri, 2012; Gemede et al., 2015). The production of this important crop aligns with the national development plan, sustainable development goals and the government priorities aimed at sustainably producing enough, nutritious and affordable food for all. Optimizing fertilizer rate during crop production is crucial to guaranteeing high yield and improve the nutrient status of not only soil but the yield (Phonglosa et al., 2015). Appropriate fertilizer programme is required during continuous crop production to guarantee increased and sustainable crop yield and minimize nutrients mining (Kutu, 2012). Hence, combined application of organic and inorganic fertilizer has been widely recommended as a viable and environmentally sustainable fertilizer programme to mitigate the effect of nutrient loss during crop production and help increase soil microbial activities (Muqtadir et al., 2019; Adekiya et al., 2018; Afe & Oluleye, 2017; Attarde et al., 2012). This study is critical to providing information regarding appropriate irrigation management strategy required by the crop for optimum production since climate change has posed a threat in vegetable crops production. The outcomes of the study will assist okra producers with the knowledge on moisture regimes for the different soil types as well as organic and inorganic fertilizer combinations to be used for optimum production of the crop. It will also assist in terms of the appropriate production practices for extended shelf life as well as increasing the availability of the crop for household consumption. It is very important for farmers to be knowledgeable on which soil type, fertilizer combination and irrigation level is necessary for optimum production of the crop to reduce excess use of any of the mentioned resources while maximizing productivity.

1.4 Aim and objectives

The study assessed the potential of combined fertilizer use and soil moisture management as components of improved agronomic practices to promote increased production of quality okra crop and availability under two soils with distinct textural types.

The following specific objectives will be undertaken:

- i. Assessed the effects of variation in soil textural types, irrigation levels and soil amendments on the growth (and phenological attributes) of okra.
- ii. Assessed the combination effects of poultry manure and inorganic NPK fertilizer on the yield and mineral quality of okra.
- iii. Evaluated the effect of different moisture regimes on the shelf life of okra fruits.
- iv. Compared the effect of soil amendments, irrigation levels and soil types on the presence of selected mineral components in okra.

1.5 Hypotheses

- H_0 : The growth, yield, and mineral quality attributes of okra as well as the fruits shelf life will not differ across the different soil textural types, soil amendments and irrigation levels.
- H_a : The growth, yield, and mineral quality attributes of okra plants as well as the fruits shelf life and will differ across the different soil textural types, soil amendments and irrigation levels.

1.6 Outline of the dissertation

This dissertation consists of six chapters, three of which (chapter 3, 4 and 5) are constructed and presented as manuscript to be submitted to journals for publication. The description of each chapter is summarized below.

Chapter 1: This introductory chapter outlines the background information, problem statement, justification, aims and objectives, and hypothesis of the study.

Chapter 2: This chapter reviews existing literatures relating to okra and its health benefits, production requirements and practices including integrating varying soil textural types with varying Fertilizer combinations and moisture regime variation effect on drought tolerance and performance of okra.

Chapter 3: This chapter titled “*Variation in soil textural types, moisture levels and soil amendments affect the growth and phenological attributes of okra*”, assesses and investigates growth and phenological response of okra to varying soil textural types and variable Fertilizer combinations under distinct moisture regime.

Chapter 4: “*Variation in soil amendments, moisture levels and soil textural types affect the yield attributes of okra*”: This chapter evaluates the yield parameters of okra exposed to two soil texture variables and variable Fertilizer combinations under two distinct moisture regimes.

Chapter 5: “*Application of variable inorganic fertilizer and poultry manure mix ratios under different soil textural types and moisture levels affect the pre & post-storage quality attributes of okra*”: This chapter analyses the mineral quality composition of okra before and after storage, as well as the weight loss of okra during storage as affected by varying moisture regimes cultivated with variable Fertilizer combinations under two soil types with distinct textural characters.

Chapter 6: “*Conclusion*”: This chapter provides the summary, conclusions and recommendations of the study.

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CHAPTER 2

Literature review

2.1 Origin and botanical description of okra

Okra forms part of the ancient, cultivated crops and is currently cultivated in several nations. Its history of distribution commenced from the Ethiopia and Sudan regions to the rest of the world are by no means certain (Kumar et al., 2013). Okra is an herbaceous hairy seasonal crop that belongs to the Malvaceae family. It is native to tropical regions of the Near East and commonly grown in the tropical and subtropical regions of the United States America. The leaves have three to five lobes with a shape of a heart. With a crimson centre, the flowers are yellow. A tapered 10-angled capsule 10 – 25 cm in length that contains multiple oval dark-colored seeds is the fruit, or pod, hairy at the base (Benchasri, 2012). Around 2 months after planting, the first okra harvest will be ready at which point, the fruits are often around 5 to 7 cm long (Ansari & Sukhraj, 2010).

Okra is among the vital indigenous vegetable crops known for its nutritional value and health benefits. The crop is popular in the Indo-pak subcontinent (Kumar et al., 2013). It is among the utmost widely recognized and used crop of the Malvaceae family. This crop, historically categorized within the genus *Hibiscus*, but later described as *Abelmoschus* for clear differentiation from *Hibiscus* (Kumar et al., 2010). Okra is widely grown in most parts of Africa to Asia, southern Europe and America; with the green fruits mostly consumed in different ways as a vegetable (Benchasri, 2012). The fruits of okra in a matured plant (Figure 2.1) have high content of vitamin, Ca, K and other minerals. Furthermore, matured fruits have crude fibre, which is valuable in the paper industry (Kumar et al., 2013). Okra can be ready for harvest at 50 – 65 days after planting (Fasunwon & Banjo, 2010).



Figure 2.1: Matured okra plant with fruits (Kumar et al., 2013).

2.2 Nutritional and mineral composition of okra

A generally grown okra under normal conditions with no fertilizer application should give us the approximate nutrient content of 87.7% water, 2.2% protein, 0.3% fats, 7.9% carbohydrates, 1.6% fibre and 0.3% ash (Adewole & Ilesanmi, 2011). According to Santos et al. (2019), the nutritional quality of the crop may be improved by applying organic poultry manure and seaweed. The oil content of the seeds can be as high as that of chicken eggs and soybeans. Mineral composition can affect the development of an okra plant; and subsequently have an effect on its overall nutritional quality (Olaniyi et al., 2010). The Soil Fertility Commission of Minas and the Agronomic Institute of Campinas (2018) recommended doses ranging from 20 – 240 kg/ha of NPK 15:15:15 and 10 – 50 t/ha of organic fertilizer. Nevertheless, these rates often require review due to the existence of newly developed cultivars with better productive traits (Santos et al., 2019) and variation in soil and climatic conditions across different agro-ecological zones.

Based on a study by Adewole & Ilesnmi (2011), 200 kg/ha NPK 12:12:17 fertilizer produced lower crude protein, crude fibre and dry matter as compared to 6.0 t/ha of manure. However, the 6.0 t/ha of manure lower ether extracts, carbohydrates, Vitamin C and ash content when compared with the 200 kg/ha of NPK 12:12:17 fertilizer. Santos et al. (2019) reported that application of 100 kg N/ha fertilizers increased the total soluble solids of okra fruits by 11%, while application of 100 kg K/ha increased the pH and titratable acids of the fruits by 3.9 and 35.1%, respectively. According to Olaniyi et al. (2010), the highest mineral composition of Fe, Mg, N, P and K was produced when 3 t/ha of organomineral fertilizers were applied.

2.3 Water requirements of okra and effects of irrigation

With the current status of climate change, it is very important to cautiously use and conserve water resources in every field of production. Water is one of the critical elements in the environment for sustainable development of a nation (Frone & Frone, 2011). Water is very important to achieve sustainable development while proper water management is an essential component of sustainability in environmental services (Ansari & Sukhraj, 2010). As a vegetable crop, okra requires an average of 25.4 mm of water weekly but may require more depending on the microclimatic condition and production regions (Afe & Oluleye, 2017). Although okra can tolerate some degree of moisture stress, introduction of irrigation water after dry conditions excites the plants and revives it for proper development (Ansari & Sukhraj,

2010). It is recommended not to irrigate at the top of plants to reduce or prevent growth of fungi which breed on wet foliage (Frone & Frone, 2011).

Water requirements increase with food demand, resulting in water resources being limited. As a result, it is essential to make the best out of the water supplied by both irrigation and rainfall to the ground to support crop production (Owusu-Sekyere & Annan, 2010). Historically, crop irrigation has been ignoring the limitations of available water sources. Hence, irrigation water is the major limiting resource to crop production in most parts of the world (Abd El-Kader et al., 2010).

Effective irrigation techniques for water use efficiency are very important in the agriculture industry in order to reduce the negative effects of climate change. Drip irrigation is considered as the most efficient irrigation system since it helps to minimize the loss of irrigation water through wind and evaporation, as opposed to surface irrigation (Patil & Tiwari, 2018). Okra production have also been recently enhanced through adoption of subsurface irrigation system, which is a low-volume irrigation practice (Mali et al., 2017). However, the use of subsurface irrigation is limited up to horticultural crops (Badr & Abuarab, 2013). According to Barkatullah et al. (2012), well-managed irrigation practices can enhance both the yield and quality of food crops. Plants need water to transport nutrients and minerals to different plant parts. Owusu-Sekyere & Annan (2010) found that the level or intensity of irrigation had an influence on the utilization of nutrients NPK by plants. They indicated that replacing 80 – 100% of moisture lost through evapotranspiration increased the utilization of nutrients, which could be due to optimum conditions in terms of aeration and moisture availability.

The analytical observations by Abd El-Kader et al. (2010) proved that drip irrigation has comparable effects to yield and water use efficiency in okra when applied at different levels. They also mentioned that different levels of irrigation had significant influence on the plant height and stem diameter. Based on findings by Patil & Tiwari (2018), application of irrigation water at 500 000 l/ha produced highest yield and plant height followed by 350 000 L/ha and 200 000 L/ha respectively while 200 000 L/ha gave the biggest stem diameter followed by 350 000 L/ha and 500 000 L/ha respectively. Results of study by Patil & Tiwari (2018) revealed that different irrigation levels and nitrogen (N) application rates significantly increased okra green fruit yield and had a remarkable effect on the biometric parameters. Chimonyo et al. (2016) found subsurface drip irrigation to produce 56.4% higher yield as compared to

conventional furrow irrigation. Hence, subsurface drip irrigation system is good for the efficient use of water as well as increasing the production of food crops.

Variation in soil types exert significant influence on moisture availability to plants (Islam et al., 2017). The ability of a soil to retain or hold moisture influences the rate at which the plants will grow depending on accessible moisture available from the soil to the plant (Hakeem & Akhtar, 2016). Soils with high clay content are likely to have more water holding capacity as compared to soils with high sand content while soils with high sand content will have high porosity and air movement as compared to that of high clay content (Wani et al., 2016). Therefore, loamy soil may result to high-quality soil with good water holding capacity as well as good porosity for easy and effective root development (Hakeem & Akhtar, 2016).

2.4 Response of okra to moisture stress

Moisture stress conditions are a bearing on the growth and development of plants, resulting to a decline in crop productivity (Anjum et al., 2017). The exponentially growing world population demands improvement in the productivity of food crops to sustain food security (Liu et al., 2015). According to Yu et al. (2015) and Mancosu et al. (2015), there are two major challenges facing the farming industry worldwide. Firstly, the need for expansion of cumulative food production for the exponentially increasing world population together with spreading scarcity of water resources. Secondly, new water resources are continuously becoming unreliable due to global climate change, contamination and overuse of water resources. Drought is the worse among abiotic stresses that hinder plant growth and development as it compromises crop productivity worse than any other ecological component depending on the genotype, duration and intensity, and plant development stage (Anjum et al., 2017).

According to Chaturvedi et al. (2019), moisture stress hinders plant leaf water potential, relative water content and transpiration rate arising from simultaneous increase in leaf temperature. The authors further argued that moisture stress during in okra is more detrimental during different plant development stages of vegetative growth, flowering and early pod filling compared to the late pod filling stage. Iqbal et al. (2020) found moisture stress to significantly decrease the relative moisture content of two okra cultivars, Nutec and Ganga. Similar findings by Deveci et al. (2017) revealed that the leaf's relative water content of okra plant exposed to drought stress was 47.58% while that of non-stressed or control plants was 98.11%. Deveci &

Celik (2016) concluded that the high crop canopy temperatures of water-stressed plants are as a result of the decreased relative water content values of leaves.

Drought stress has been reported to compromise the membrane stability index of okra (Chaturvedi et al., 2019). This statement is in line with earlier findings by Kaya & Dasgan (2013), who reported that moisture stress decreases membrane stability index by approximately 57.6% in groundnuts. The membrane stability index of plants is mostly vulnerable to drought stress at vegetative stage than it does at late-pod filling stage (Altaf et al., 2015). The decrease in membrane stability index causes a leakage of ions and electrolytes in the cell membranes, resulting in reduced photosynthesis and the overall production of the plant (Dastborhan & Ghassemi-Golezani, 2015). Furthermore, the growth and development of plant leaves possess high sensitivity to moisture stress because its photosynthetic capacity depends on improved leaf area (Anjum et al., 2017). Several elements such as diminished cell expansion, decrease in cell division, mortality of apical parts of leaf and leaf rolling lessens the leaf area significantly (Altaf et al., 2015). Each of these processes persists in moisture-stressed plant and are regarded as essential basis in gathering crop yield through inhibition of net photosynthesis (Furlan et al., 2012).

Mkhabela et al. (2022) reported that drought induced reduction in net photosynthesis at different growth stages was attributed to a decrease in leaf expansion causing reduced leaf area. According to Chaturvedi et al. (2019), both stomatal and non-stomatal limitations may occur to photosynthesis under drought stress in okra, as reduction in photosynthesis is largely attributed to reduced stomatal conductance (Buckley, 2017). Reduced leaf relative water content (Badr & Brüggemann, 2020) and the reduction in membrane stability index (Deveci & Celik, 2016) suggest that other biochemical processes beside CO₂ uptake might be damaged. Furthermore, the role of drought-induced stomatal closure, which limits the uptake of CO₂ by leaves may also possibly lead to increased susceptibility to photo-damage (Iqbal et al., 2020).

Several studies have reported the effects of drought stress on fruit yield reduction to be high on a range of agricultural and horticultural crops such as sorghum, tomato, peach and strawberry (Sarshad et al., (2021); Liang et al., (2020); Badr & Brüggemann, (2020)). Similar results were reported by Altaf et al. (2015) in okra pods, where a reduction of approximately 69.2% in the number of okra pods was recorded when plants are exposed to drought stress. The yield reduction in okra to drought stress is attributed to alteration disturbing plant process for growth and carbon assimilation at specific growth stage (Furlan et al., 2012). The extent of

yield reduction in okra due drought stress depends on the phenological age at which the stress is imposed as well as the cultivar (Mkhabela et al., 2022).

Reportedly, drought stress reduces the number of meristems due to slowed cell division resulting in reduced flowering capacity and pod formation (Mancosu et al., 2015). Furthermore, drought stress reduces the number of seeds per pod as well as the size and length of the pods (Deveci et al., 2017). According to Ezech & Adejumo (2020), longer pods are more desirable as they allow for ovule development and accommodate more ovules inside the ovary, hence higher number of seed production. The positive correlation between fresh pod length and pod yield per plant under stressed conditions indicates that pod characteristics are useful for direct selection to improve the fresh pod yield in okra (Iqbal et al., 2020). Therefore, proper irrigation management and improved water usage techniques are required to maximize the yield of the plants.

2.5 The importance of okra

Okra is a very important vegetable crop in the economy of the African and Asian countries (Gemede et al., 2014). It is a multi-purpose crop due to its different usable parts such as the leaves, pods, flowers, seeds and stems (Mihretu et al., 2014). Each part of okra has its purpose and benefits and can be used separate from the other parts. Furthermore, all of the okra parts have medicinal benefits when consumed. Some of the okra's health benefits are that is rich in antioxidants that prevent diseases, inflammation and contribute to heart and brain health. It can be boiled, and the liquid from the boiled okra can be used to add flavor to stews and sauces. The liquid from okra has medicinal benefits when used as blood volume expander or plasma replacement (Sathish & Eswar, 2013). Recently, we see okra in water bottles everywhere (gyms, workplace, gathering etc.) because of the wide spread awareness of the benefits brought by okra to the health of humans. In the past, okra was only used as a relish, but it is recently being consumed in multiple ways which includes salads, relish, okra water etc. (Mihretu et al., 2014).

2.5.1 Nutritional benefits of okra

Abelmoschus esculentus is more of a diet rather than a staple food (NRC, 2006). It plays a critical role in a human diet by providing proteins, and vitamin C in bulks (Dilruba et al., 2009). The lipid components from okra have a great potential to contribute to the nutritional value of almost all kinds of food. In addition, carbohydrates are available in the form of mucilage from the leaves of okra (Gemede et al., 2014). The main composition of sugar units and amino acids

available in the fruits of young okra are 24.6% galactose, 21.8% rhamnose, 27.1% galacturonic acid and 11.4 % amino acids (Benchasri, 2012). Okra seeds contain 2.0 % protein and 0.19 % oil underscoring the importance in both the food and oil industries (Kumar et al., 2010). Dried okra seeds are highly nutritious and used not only in making vegetable curds but also used as coffee additives or substitutes (Ansari & Ismail, 2001). Okra is rich in vitamin C, a water-soluble nutrient that boost humans' immune function (Benchasri, 2012).

2.5.2 Medicinal benefits of okra

The consumption of vegetables has significant benefit of contributing to the reduction in the risk of chronic diseases (Lengsfeld et al., 2004). Such a benefit is derived from the presence of its antioxidant activities. The antioxidant properties found from antioxidant compounds in vegetables such as okra are associated with the presence of vitamin C and E, carotenoids, and bioactive compounds, mostly flavonoids (Gemedede et al., 2015). However, less information is available on the antioxidant capabilities of major bioactive compounds from an okra seed (Oyelade et al., 2003). Okra also has high fibre, vitamin C, and folate content that help to promote human health (Ansari & Sukhraj, 2010).

The high fibre content found in okra help regulates the rate at which sugar is absorbed from the digestive system; and therefore, aids in stabilizing blood sugar levels (Liao et al., 2012). The frequent consumption of okra also reduces the chance of kidney problems, as most cases of kidney diseases are associated with blood sugar levels (Gemedede et al., 2014). Furthermore, okra can also be useful for treating gastrointestinal problems. The polyoses available in young okra's pods have a high content of antiadhesive properties that removes the adhesive between bacteria and the stomach tissues, terminating the cultures from spreading. Eating more of this crop can keep our stomach free from a number of bacteria (Messing et al., 2014).

Okra can also be useful for the health of a pregnant woman by generating and preserving new cells and foliate substance for optimum pregnancy (Gemedede et al., 2015). The high content of foliate in okra is useful for the foetus development during pregnancy. Folate also aids in the fetus' brain growth and development (Georgiadisa et al., 2011). The soluble fibre within okra lessens the level of blood cholesterol and therefore reduces the chances of heart diseases. Therefore, the high intake of okra improves heart health (Gemedede et al., 2014). The consumption of okra helps to improve good eyesight (Sabitha et al., 2011).

2.6 Production status of the crop

Less attention has been given to the production of okra over the past centuries, however, the crop has recently been given more attention as more people learn about its importance and the nutritional and medicinal value (Adekiya, et al., 2019). According to Mishra, et al. (2017), over 98.9 % of okra is cultivated solely in the developing countries of the African and Asian continents. Its production is estimated to occupy an area of about 1.83 million ha with 9.62 million metric tons of yield in average per year (Afe & Oluleye, 2017). According to Mishra et al. (2017), 72% of the total world production of okra is produced from India, from an area of 0.5 million ha. Uttar Pradesh, Odisha, Bihar, Andhra Pradesh and West Bengal are the major okra growing states in India, and most of the okra produced is exported to United Kingdom, Europe and America.

Okra can be grown in almost every part of the state of Florida in the USA; however, it is commercially grown in the Dade area and surrounding countries (Freidenreich et al., 2022). The commercial production of okra grown in USA was estimated to occupy 607.03 ha with 9105.45 tons of yield in 2004 where majority was produced in southern Florida (Mishra et al., 2017). Soil physical and chemical properties such as nutrient status and organic matter influence the production of crops in terms of growth, yield and quality (Adekiya et al., 2019). The west and central African soils have less organic matter and is therefore prone to soil degradation (Afe & Oluleye, 2017). With the exponential growth in human population and urbanization, market-oriented okra production is in peri-urban zones (Layade et al., 2017). Okra production in the west and central Africa is dominated by men (Choudhary et al., 2015).

2.7 Challenges in the cultivation of okra

The genetic base of African species diversity is slowly but surely being devastated, primarily due to the introduction of genetically modified organisms (GMOs) crops substituting indigenous varieties thus constituting the primary roots of genetic erosion in plants around the globe (Shiundu & Oniang'o 2007). Another reason is that most researchers prefer to work on well-established and exotic vegetables compared to indigenous vegetables as the result very little information is available on okra (Fajinmi & Fajinmi, 2010).

Generally, traditional knowledge about indigenous vegetables is limited and only understood by the old age group (Zobolo & Mkabela 2006; Voster et al. 2007; Lewu & Mavengahama 2010). The current youth has shown no awareness in native crops, they regard them as poverty and favor western foodstuff endorsed by the media (Voster et al. 2007). Thus, if youth does not

take part in promoting these vegetables the possibility of them being eroded is very high since the future is in their hands (Benchasri, 2012).

The other main challenge in the production with okra and other crops is climate change (Jiang et al., 2012). The exponential growth of the world's population creates more problems in the agricultural science industry by increasing the demands for agricultural products. Strategies for meeting the population's demand and food security need to be put in place to balance the possible plant manufacturing and the call for plant products at national and international level (Spiertz, 2013).

2.7.1 Pests and diseases in okra production

Abelmoschus esculentus is prone to several pests and diseases (Benchasri, 2012). Different stage of growth of the crop is prone to different types of pests and diseases (Fasunwon & Banjo, 2010). Insects that are mostly a problem during seedling stage are mostly crickets, whereas thrips, aphids and whitefly cause problems during vegetative growth stage (Fajinmi & Fajinmi, 2010). The occurrence of most disorders is the same in almost all areas where okra is grown. The yellow-vein mosaic (Figure 2.2) is the most occurring disorder across all growing areas. This virus causes serious loss of quality and yield by reducing plant growth and photosynthesis rate (Benchasri, 2012).



Figure 2.2: Okra plant with yellow-vein mosaic (Benchasri, 2012).

Okra is also prone to fungal diseases such as damping-off, vascular wilt, *Cercospora blight* and powdery mildew. Flea beetles are transmitters of mosaic virus which is widespread in Africa (Kumar et al., 2013). However, its damage is less important than those of leaf curl disease disseminated by whitefly. These diseases can be easily dealt with through the control

of their vectors. Nematodes are usually the major problem in the cultivation of okra, and it can be controlled by the use of crop rotation and applying a lot of organic fertilizer (Kumar et al., 2013).

2.7.2 Effect of variable climatic conditions

Okra is a tropic to sub-tropical crop which is prone to frosts, lower temperatures, water logging and drought conditioned environments. Different geographical areas have different climatic conditions, at which certain adapted characteristics specific to the area are required (Kumar et al., 2013). However, climate change has a bad influence on such characteristics, and therefore disturbs the development and survival of okra. Climate change is problematic to agriculture in both direct and indirect ways, such that the emergence of new pests and diseases are as the result of climate change (Raja et al., 2018).

Lower temperatures are the major cause of failure in okra production which causes poor germination and stand establishment which leads to low productivity (Raja et al., 2018). Okra seed requires a temperature range of between 21 and 35°C for germination, thus poor germination is common under temperatures below 21°C (Kumar et al., 2013). Climate change is also known for its substantial effects on water availability and soil moisture. Thus, inadequate and excess soil moisture contributes to the poor and erratic germination of okra seeds (Marcinkowski & Piniewski, 2018).

2.8 Effect of soil amendment on okra production

Fertilizer application improves both the yield and nutritional quality of an Okra crop (Meena & Bhati, 2016). Farmers can choose to use either organic or inorganic fertilizers, or both. The most critical elements available in inorganic fertilizer are Nitrogen, Phosphorous and Potassium. Each element has its own purpose in the growth and development of a plant. These elements are required at different growth stages of the plant (Santos et al., 2019). Over use and excess of these elements in the soil can result to both poor plant growth and poor soil health. It can also result to reduced soil productivity and environmental pollution (Attarde et al., 2012).

The element responsible for plant growth in a chemical fertilizer is mostly nitrogen. Chemical fertilizers have a high content of nitrogen available for the plants (Fajinmi & Fajinmi, 2010). The number of leaves in an okra plant can be at maximum when applied with chemical fertilizers that consist of high amounts of nitrogen content, and rapid plant growth can be experienced (Ansari & Sukhraj, 2010).

Chemical fertilizers also have higher amounts of potash, nitrate and phosphate content which increases plant growth rapidly (Attarde et al., 2012). As much as organic fertilizers are releasing nutrient at lower rate than inorganic fertilizers, they have positive effects to the growth and yield of plants. Farmyard manure and vermicompost have the ability to increase growth and yield of many plants. This can be as a result of the good nutrient supply by vermicompost to the soil. Organic fertilizers also improve the porosity of the soil, which improves the capacity of the soil to hold moisture (Narkhede et al., 2010).

According to Meena & Bhati (2016), the application of NPK in the cultivation of okra resulted to a massive difference in the heights of okra plants after 40 days of planting as equated to the control treatment. Maximum height of the plants was obtained in the plot applied with nitrogen, phosphorus and potassium, and minimum in the control plot. The use of poultry manure (Table 1) is capable of increasing the number of leaves and plant height by approximately 39.4%, and therefore increase the rate of photosynthesis (Tiamiyu et al., 2012). However, Abd El-kader et al. (2010), reported that applying organic poultry manure results to an increase of 27.4% plant height and 110.9% in stem diameter (Santos et al., 2019).

2.8.1 Effects of soil amendment on the yield of okra

Okra can be grown and harvested without the application of any fertilizer, but to increase the production of okra, the application of organic fertilizer (poultry dung) or chemical fertilizers (NPK) is very necessary and relevant (Adekiya et al., 2018). Furthermore, the different levels of NPK in chemical or inorganic fertilizers had a significant impact on the number of fruits, size of fruits and the yield of the crop (Meena & Bhati, 2016). The increased availability of phosphorus in the fertilizer applied aid in increasing the number of leaves in each plant, thus increasing the rate of photosynthesis by the plant (Santos et al., 2019).

The application of urea to okra produces the best number of fruits, growth and mineral composition of the crop. However, if the focus is only on production, low application amounts are recommended, but if the goal is to produce fruits with good nutritional quality, high amount of urea application are recommended (Adekiya et al., 2018). According to Attarde et al. (2012), the combination of organic and inorganic fertilizers results to the production of the highest number of flowers per plant, and therefore resulting to the highest number of pods in an okra crop (Santos et al., 2019).

2.9 Factors affecting the shelf life of okra after harvest

Okra is a vegetable crop of great importance to the health of humans; hence, it is important to preserve and conserve the quality of the crop to prolong its availability. It is one of the vegetable crops that get spoiled quickly after harvest (Olivia, 2020). According to Indore et al. (2016), okra can last for about 24 hours at room temperature after harvesting. However, when they are properly refrigerated, okra can retain its freshness and quality for about 2 to 3 days after harvest. When okra is properly harvested and packaged, it can last for about 9 months in the freezer (Ansari & Sukhraj, 2010). The quality of stored okra decreases with increasing temperatures and humidity (Tekale et al., 2016). Therefore, it is not recommended to store okra pods at room temperature unless it is going to be cooked with a couple of hours. Additionally, when okra is stored on freezer and the freezer is opened and closed often, the shelf life of the crop is drastically shortened (Olivia, 2020).

According to Perishables Handling (2018), a very good quality of okra pods can be preserved for up to 10 days at temperatures ranging from 7 – 10 °C. When stored at higher temperatures, okra quality deteriorates quicker due to moisture loss, yellowing and decay due to microbial attack. Chilling injury is induced when the pods are stored in temperatures below 0 °C (Dhumal, 2016). To enhance the quality of okra, as well as improving the shelf life, it could be precooled with forced-air and hydrocooling method which reduce the respiration rate as well as reducing the production rate of ethylene and its response to ethylene (Babarinde & Fabunmi, 2009).

The shelf life of okra pods is also influenced by the packaging method before storage. Vegetables such as okra and tomatoes have higher water contents which makes them to be highly perishable and susceptible to rapid deterioration soon after harvesting (Babarinde & Fabunmi, 2009). They therefore should be packaged and stored properly if they are not going to be consumed immediately. According to Puiatt (2008), harvested okra becomes fibrous and unsuitable for direct use 2 days after harvesting. Hence, proper packaging and storage is required to better the quality and extend shelf life for more additional days.

Finger et al. (2008) reported that okra packaged in Low Density Polyethylene (LDPE) bags had better quality and extended shelf life by 3 days, followed by plastic sieve over-wrapped with LDPE. Indore et al. (2016) proved that the shelf life of okra pods was 3 days at room temperature, 9 days at zero energy cooling chamber and 15 days at refrigerated storage when a 400-gauge polyethylene bag is used.

Summary

Okra production in South Africa is at minimal level, often confined to small-scale and subsistence production level. This production scale has resulted in limited availability of the crop in the market. Challenges associated with the reduced availability of okra in the market based on literature information include poor soil fertility status, which is compounded by the none to sub-optimal or inappropriate use of fertilizers (Mkhabela et al. 2022; Ya-wei et al. 2019; Meena & Bhati 2016), and soil moisture constraint occasioned by low inherent soil moisture reserve and drought due to climate change (Chaturvedi et al. 2019; Altaf et al. 2015). Furthermore, okra fruits are highly susceptible to spoilage under poor storage conditions due to the high moisture content, thus maximum care is required to preserve them, preferably at temperatures between 7 and 10 °C (Perishables Handling 2018). Hence, increase production and availability of this important vegetable crop may be achieved by employing appropriate agronomic strategy that integrate optimal fertilization and irrigation use under different soil types and complemented with appropriate storage and packaging systems.

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CHAPTER 3

Variation in soil textural types, moisture levels and soil amendments affect the growth and phenological attributes of okra

Abstract

A greenhouse trial was initiated to assess the combined effect of variable fertilizer mix ratios and soil moisture levels on the performance of okra grown on two soils with distinct textural types. The factorial experiment was fitted into a nested design with 4 replications. The soil textural types (sandy loamy and clay loamy) and soil moisture regimes (< 30% FC and >80% FC) constituted main and sub-plot, respectively while soil amendments comprising of the six Fertilizer combinations constituted the sub-sub plots. The Fertilizer combinations included 100% poultry manure (PM) and 100% inorganic NPK fertilizer applied based on the recommended rates of 15t/ha and 100kg/ha, respectively, and different mix ratios of PM and inorganic NPK fertilizers (75:25, 50:50, and 25:75). An unamended control treatment was included as standard check. Results revealed that integrated use of PM and NPK fertilizer with 75:25 mix ratio gave the best okra performance and was statistically comparable to the sole (100%) PM rate. Integrated use of PM and inorganic NPK fertilizer at 75:25 mix ratio resulted in increased plants' growth, and performed better in both soil moisture levels, as well as in both the sandy loam and clay loam soils. However, better performance was recorded on clay loam soil than in the sandy loam soil. The 50:50 PM and inorganic NPK fertilizer treatment gave statistically superior but comparable performance to the sole (100%) inorganic NPK fertilizer treatment.

Keywords: Poultry manure, NPK fertilizer, okra, drought, crop performance.

3.1 Introduction

The potential of okra (*Abelmoschus esculentus*) to reduce the chance of kidney problems due to blood sugar levels arising from frequent consumption is well documented (Gemede et al., 2015; Meena & Bhati 2016; Akhter et al. 2019; Santos et al., 2019). Similarly, the consumption of okra has also been reported to help prevent gastrointestinal problems (Gemede et al., 2014). The performance and growth of okra are generally enhanced by the addition of fertilizers such as manure and inorganic NPK fertilizers to the soil. Sharma et al. (2020) found that applying nitrogen (N) aids in chlorophyll formation and the uptake of other nutrients, benefits in the processes of photosynthesis, and ultimately increases the overall crop growth. Similarly, the

application of P and K from either organic or inorganic fertilizer source aids in early root formation and stimulates blooming and seed formation and increase the tolerance of the crop to disorders and insects attack (Adewole & Ilesanmi, 2011). Furthermore, the ability of soil to preserve water for plant use to influence crop growth depend on the amount of moisture that the soil can be preserved and for how long (Tang et al., 2019). The scarcity or limited availability of okra in the market is associated with its limited production particularly in South Africa. Unlike other field and horticultural crops that have commercial production, okra production is largely grown by smallholder farmers whose farm sizes are generally less than one hectare with most times suboptimal to no fertilizer use to guarantee increase and sustainable crop yield (Kutu, 2012). Furthermore, okra as a fresh and perishable fruit vegetable crop has short shelf life and is easily susceptible to microbial attack and spoilage leading to losses (Adekiya et al., 2019).

According to Courtwright & Findlay (2011), loamy soil represents an excellent soil textural type with moderate water holding capacity and ability to adequately supply crop with water with reduced chances of flooding. Conversely, clay soil has high water holding capacity that can potentially lead to flooding, death of crops, inhibits aerobic respiration and loss of soil microbes (Tang et al., 2019) that ultimately limits energy metabolism and restricts the developmental processes for seed germination (Wang et al., 2019). However, sandy soils possess poor nutrient availability and water holding capacity (Gao et al., 2018).

Utilization of the optimum fertilizer rate is essential for maintaining the soil nutrients level to promote crop growth and development, and crop yield. However, reports on the optimum rates of organic and inorganic fertilizer for okra growth in South Africa are scanty. Different fertilizer grades are currently available in South African market for use by farmers, which include the NPK 2:3:2 (33), Urea (46% N), and Chloride (60% K) Hence, this study investigated the effect of integrated use of poultry manure and NPK 2:3:2 (33) fertilizer on the growth of okra grown on soils with different textural characteristics and moisture regimes. I hypothesized that the growth and phenological attributes of okra plants will not differ across soils with different textural types and irrigation regimes following amendment with various mix ratios of poultry manure and inorganic NPK fertilizer.

3.2 Materials and Methods

3.2.1 Description of the experimental site

The study was conducted under greenhouse condition at the Mbombela Campus of University of Mpumalanga (25.4365°S, 30.9818°E; 677 m asl) in Mpumalanga Province, South Africa. The campus is situated in the Lowveld region of Mpumalanga Province, which has humid sub-tropical climate with hot and rainy summers, and mild and dry winters (Masereka et al., 2018). The annual rainfall of the area is approximately 750 mm, and most of the rain is received between December and March. On average, these months record 14 to 15 rainy days a month. Temperatures range from a minimum of 10°C to a maximum of 32°C and is rarely below 7°C and/or above 40°C (Masereka et al., 2018). The average winter temperatures vary between 10 °C and 27°C, whereas the average summer temperatures vary between 18°C and 32°C (Masereka et al., 2018). It is advisable to grow crops like okra during the summer season, where there is more rainfall and warmer temperatures.

The poultry manure used for this study was sourced from a nearby battery cage system of a local farmer containing old layers while the NPK 2:3:2 (33), Urea (46% N) and potassium chloride (60% K) fertilizers as well as the okra (Clemson spineless) seeds (Figure 3.1) sown were bought from Hinterland, which is an agricultural input market store in Mbombela. The two soil types used for the experiment were collected from the University farm and from a farm in Barberton from a plot that has no recent record of cultivation and/or amendments. The topsoil was collected (0-20 cm depth) using a hand spade and sieved to remove plant residues, weed seeds, stones and other unwanted materials, air-dried and sterilized before use. Chemical analysis of the poultry manure sub-sample was done prior to use. The soil was subsampled for both chemical and physical analysis.



Figure 3.1: Okra seeds (Source: *Hinterland, Mbombela, South Africa packaged seed for sale*).

3.2.2 Description of the greenhouse trial, treatments, research design and trial layout.

The greenhouse factorial experiment was fitted into a nested design with 4 replications. It comprised of two soil textural types (sandy loamy and clay loamy), two irrigation regimes and six fertilization levels as soil amendments. The irrigation regimes imposed after establishing the field capacity (FC) of each soil comprised of (i) non-stressed plants with regular irrigation maintained at $\geq 80\%$ FC moisture content, and (ii) severe moisture stress plants with $\leq 30\%$ FC moisture content. Imposition of the moisture stress conditions was for a period of 21 days at the commencement of the reproductive (first flowering) growth stage. The fertilization combinations comprised of the optimum poultry manure blanket rate of 15 t/ha based on the recommendation by Santos et al. (2019) and the 100 kg/ha of NPK recommended by Muqtadir et al. (2019) and Afe & Oluleye (2017). The optimum inorganic fertilizer combinations were obtained using a mixture of inorganic NPK fertilizer 2:3:2 (33), Urea (46% N) and potassium chloride (60% K). Other fertilizer treatments comprised of different mix ratios of 50:50, 75:25 and 25:75 poultry manure and inorganic fertilizers based on the optimum rates for both fertilizer types. There were four (4) replications for each treatment factor.

Ten kilograms of the pasteurized soil was weighed and transferred into a 30 cm diameter plastic pot for use in the experiment. The required quantity of the Fertilizer combinations based on the intended treatments to be used as soil amendments were similarly weighed. The weighed soil and various soil amendments were thoroughly mixed on a polyethene sheet based on individual treatment and thereafter transferred into each well-labelled pot. The pots were irrigated to nearly 90% field capacity and allowed to stand for 7 days for mineralization of the poultry manure before seed sowing. Four okra seeds were sown per pot and the seedlings thinned to two plants per pot at 2 weeks after seedling emergence (WAE). Inorganic NPK fertilizers were applied as side dressing at 2 WAE based on the specified treatment. The experiment was terminated after 14 weeks.

3.2.3 Soil textural determination and chemical characterization of the soil and poultry manure

The soil textural classification was determined using the hydrometer method of analysis. 40 g of soil was weighted using a weighing scale, it was therefore added to a 600ml beaker. Distilled water was added up to 300 ml mark and was stirred using a magnetic stirrer. To avoid excessive foaming, hydrogen peroxide was carefully added in 20 ml increments until reaction was slow, indicating completion. The sample was left at room temperature for 48 hours, and it was heated

on a hot plate at 80°C for 3 hours to remove excess hydrogen peroxide. The solution was then added in to a 1000 ml sedimentation cylinder, and distilled water was added until a 1000 ml mark. The sample was then thoroughly mixed by covering the open end of the sedimentation cylinder with a hand and lift up and down. The hydrometer was slowly inserted into the cylinder after 10 seconds. The readings were recorded at 30, 50, 70 and 90 seconds. The chemical characterization of the soil and poultry manure was done at the Agricultural Research Council, Institute of Tropical and Sub-tropical (ARC-ITSC) laboratory facility, Nelspruit.

3.2.4 Data collection

The parameters that were measured to address the study objectives were number of leaves, leaf chlorophyll content, days to first flower initiation and 50% flowering. Growth and phenological attributes were measured at weekly intervals from 9 WAE representing the time for the commencement of moisture stress. All data sets required for growth parameters were measured and recorded during the 21 days of stress period, which include the mean number of leaves for 3 weeks (9 – 11 WAE) and leaf chlorophyll content for 4 weeks (9 – 12 WAE). Parameters such as number of leaves were counted, and chlorophyll content was measured using an OPTI-SCIENCES (CCM-200 plus) chlorophyll content meter. The phenological data including number of days to flower initiation and day to 50% flowering were observed and recorded for each treatment.

3.2.5 Statistical analysis

Data collected were subjected to normality test and homogeneity of variance before analysis of variance (ANOVA) using Sharpiro-Wilk test on Statistix-10. Analysis of the repeated data measured involved the use of Multifactorial ANOVA (MANOVA) model fitted into nested design. The effect of fertilizer combinations, moisture regimes and soil textural variation on the measured growth and yield variables after the moisture stress imposition were analyzed using the linear mathematical model:

$$Y_{ijk} = \mu + F_i + M_j + S_k + (F \times M)_{ijk} + (F \times S)_{ijk} + (M \times S)_{ijk} + (F \times M \times S)_{ijk} + E_{ijk},$$

where: Y_{ijk} = measured parameters, μ = population mean, F_i = Fertilizer combinations effect, M_j = Moisture effect, S_k = soil types effect, $(F \times M)_{ijk}$ = interaction effect of Fertilizer combinations and moisture regimes, and $(F \times S)_{ijk}$ = interaction effect of Fertilizer combinations and soil types. Others include $(M \times S)_{ijk}$ = interaction effect of moisture regimes and soil types, $(F \times M \times S)_{ijk}$ = interaction effect of Fertilizer combinations, moisture regimes and soil types, and E_{ijk} = random error effect. The test of significant difference between treatment means was

at 0.05 probability level while Duncan Multiple Range Test (DMRT) was used for mean comparison.

3.3 Results

3.3.1 Laboratory analysis of the poultry manure and soil samples used for the trial.

Results of chemical analysis of the poultry manure used in the study (Table 3.1) show that it contains high level of essential macro-nutrients namely N, P, K and Ca required by plants. The measured N and P content in the poultry manure represents an elevated level in relation to the critical level of 0.2% for total N, 10.0 mg/kg for total P recommended for okra production by Adekiya et al. (2019). The poultry manure also contains high adequate concentration of Zn, Mn, and Fe as well as boron that are considered essential for root elongation and tissue differentiation (Broadley et al., 2012).

Table 3.1: The chemical composition of the poultry manure used.

Parameter	Values	Unit
Nitrogen	3.07	%
Phosphorus	1.58	%
Potassium	2.13	%
Calcium	4.98	%
Magnesium	0.703	%
Zinc	322.5	mg/kg
Copper	58.3	mg/kg
Manganese	695	mg/kg
Iron	776.8	mg/kg
Boron	96.4	mg/kg

The laboratory results of pre-planting soil samples collected from both UMP and Barberton farms (Table 3.2) revealed that the textural classes of soils from both farms are distinct namely, sandy loam and clay loam, respectively. The results also reveal that both the soils are acidic with the soil from Barberton being more acidic. The Barberton soil contains higher Ca, Mg, K, Na and Al concentrations than the soil from UMP while the UMP soil has higher available P that is well above the threshold/critical level of 10 mg/kg defined by Adekiya et al. (2019). According to the soil critical/threshold levels of 3.0% OM, 0.2% total N, 10.0 mg kg⁻¹ available P, 0.16 - 0.20 cmol/kg exchangeable K, 2.0 cmol/kg exchangeable Ca, and 0.40 cmol/kg exchangeable Mg recommended for crop production in ecological zone of Nigeria (Akinrinde and Obigbesan 2000), it was necessary to add fertilizers to both the used soils. Specifically, the

reported available P level in both soils indicate sub-optimal (i.e., ≤ 20 mg/kg) level in Barberton soil but above the optimal level of ≥ 28 mg/kg in the UMP soil (Fertasa, 2016). The Al concentration in Barberton soil is more than 55% higher than the concentration in UMP soil. Aluminum (Al) concentration in acidic soil is regarded as the primary limitation to crop productivity worldwide (Singh et al., 2017). According to Ghazali et al. (2020), soluble Al is present in the soil when the pH begins to drop below pH 6.0 but mostly inconsequential until it drops below pH 5.5. The pH level of the used soil is within the recommended range of 5.8 – 6.8 for okra by Brandenberger et al. (2018).

Table 3.2: Results of laboratory analysis of the soil samples prior to planting

Parameter	Values		Unit
	UMP	Barberton	
Clay	15.4	31.4	%
Silt	19.4	39.2	%
Sand	65.2	29.4	%
Textural class	Sandy loam	Clay loam	
pH	6.27	5.79	pH
Available phosphorus	31.51	8.47	mg/kg
Exchangeable potassium	96	131	mg/kg
Exchangeable calcium	459	1316	mg/kg
Exchangeable magnesium	117	463	mg/kg
Extractable sodium	8	17	mg/kg
Extractable aluminum	9	14	mg/kg

3.3.2 Main treatment effects

Figure 3.2 below revealed that the mean number of leaves per plants on the sandy loam soil from the non-stressed pots with fertilizer application remain fairly stable during the period of moisture stress (A) while the stressed plants (B) decreased sharply across all fertilizer treatments except the 50:50 PM and inorganic NPK fertilizer treatment with 9.1% increase at 11 WAE.

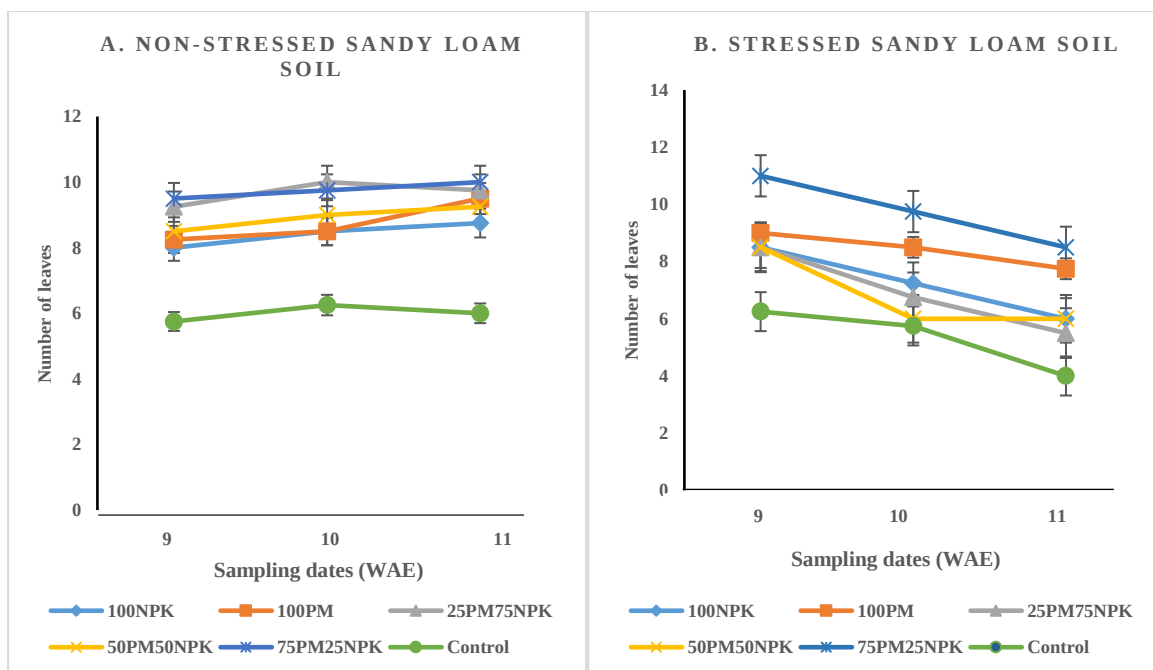


Figure 3.2: Effect of different fertilizer combinations on number leaves of okra under the two moisture conditions.

Figure 3.3 below shows the response of okra leaf chlorophyll content to different fertilizer treatments under non-stress and moisture stressed plants grown on sandy loam soil. The results revealed that the leaf chlorophyll content from the 25:75 PM and inorganic NPK fertilizer combination decreased from 9 – 12 WAE on the moisture stressed treatment, whereas it increased from 10 – 12 WAE on the no moisture stress treatment. The chlorophyll content measured from the 25:75 PM and inorganic NPK fertilizer treatment gave the best performance under both soil moisture conditions. The results in the graph also revealed non-consistent and fluctuating chlorophyll content for the different fertilizer treatments under both soil moisture conditions. The results revealed that the variation in the fertilizer mix ratios had significant ($p \leq 0.05$) effect on the chlorophyll content under both soil moisture conditions. The mean chlorophyll content measured from okra plants treated with 75:25 and 50:50 fertilizer mix ratios are statistically comparable under non-stressed plants.

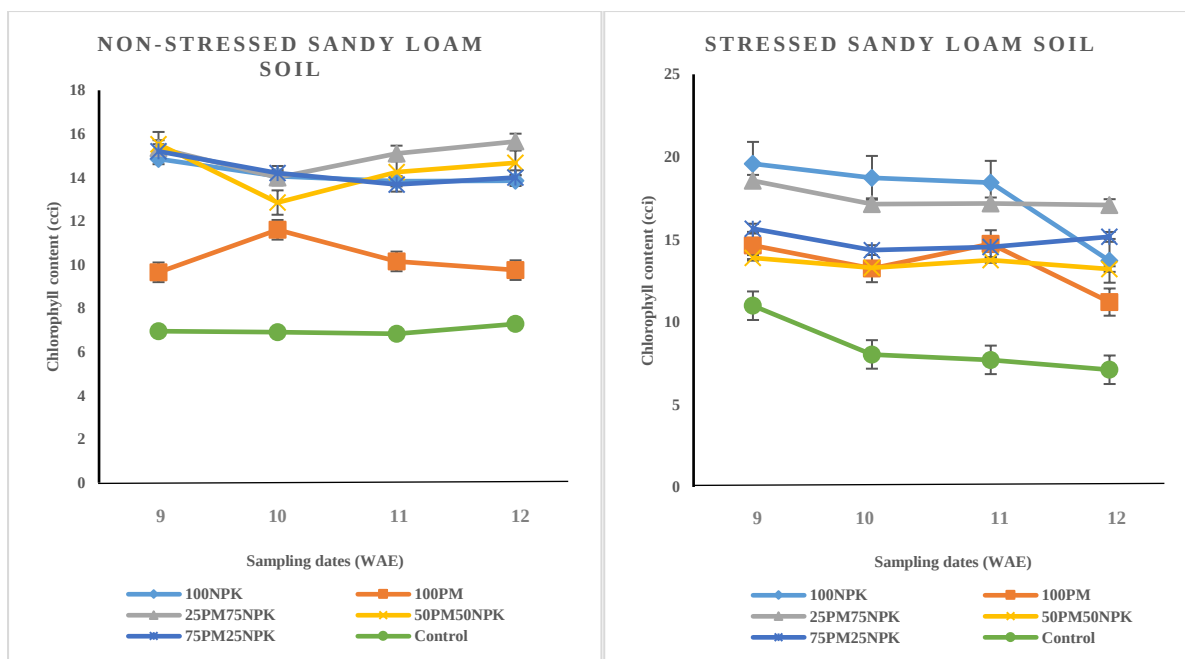


Figure 3.3: Effect of different fertilizer combinations on leaf chlorophyll content of okra under the two moisture conditions.

Figure 3.4 below revealed that the mean number of leaves per plant from the stressed plants started decreasing immediately after the introduction of moisture stress at 9 WAE whereas, from the non-stressed plants the number of leaves increased while it remained constant to some treatments. With reference to the above results, the 100 PM treatment gave the highest number of leaves from the stressed plants during the stress period, whereas it gave the lowest number of leaves from the non-stressed plants during the same period. The 75:25 PM and inorganic fertilizer gave the highest number of leaves than the other mix-ratio treatments on the stressed plants, however, it did not differ statistically with the 25:75 PM and inorganic fertilizer. The 50:50 PM and inorganic fertilizer treatment gave the highest mean number of leaves within the non-stressed plants, which is however, not statistically different from the 100 NPK treatment. The results also reveal that induced moisture stress decreased the mean number of leaves per plant. The statistical analysis revealed that there was a significant difference between the stressed and non-stressed treatments during the stress period ($p \leq 0.05$).

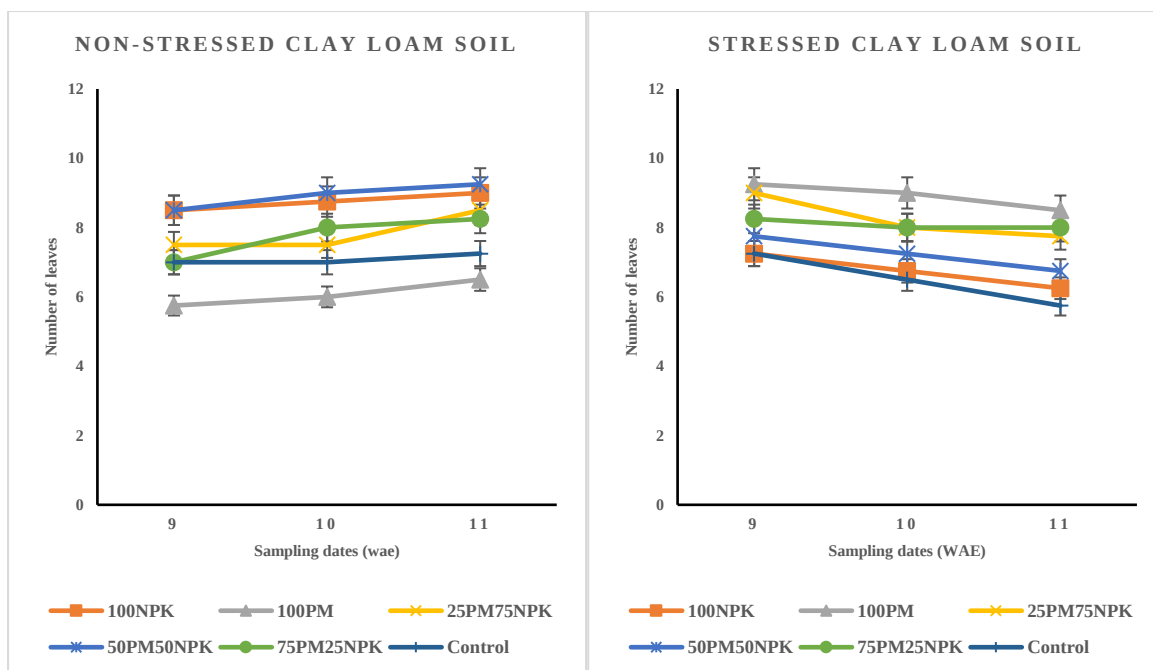


Figure 3.4: Effect of different fertilizer combinations on number leaves of okra under the two moisture conditions.

Figure 3.5 below shows the response of okra leaf chlorophyll content to different fertilizer treatments under non-stress and moisture stressed plants grown on clay loam soil. The results revealed that the chlorophyll content from the 50:50 and 75:25 PM and inorganic NPK fertilizer decreased from 9 WAE until 12 WAE on the moisture stressed treatment. On the no moisture stress treatment, the chlorophyll content from the same treatments decreased from 9 WAE to 10 WAE, and there was a slight increase from 10 WAE until 12 WAE. The chlorophyll content measured from the 25:75 PM and inorganic NPK fertilizer treatment gave the best performance under the non-stress treatment. It also performed better than the other mix ratios under the moisture stress treatment, it however did not differ statistically from any of them, meaning there was no significant difference between the mix ratio treatments. The results in the graph also revealed non-consistent and fluctuating chlorophyll content for the different fertilizer treatments under both soil moisture conditions. The results revealed that the variation in the fertilizer mix ratios had significant ($p \leq 0.05$) effect on the chlorophyll content under both soil moisture conditions. The mean chlorophyll content measured from okra plants treated with 75:25 and 50:50 fertilizer mix ratios are statistically comparable under both soil moisture conditions. The chlorophyll content of the mix ratios decreased on the moisture stress treatment, whereas it fluctuated on the no moisture stress treatment. Meaning moisture stress has a negative effect on the chlorophyll content of okra plants.

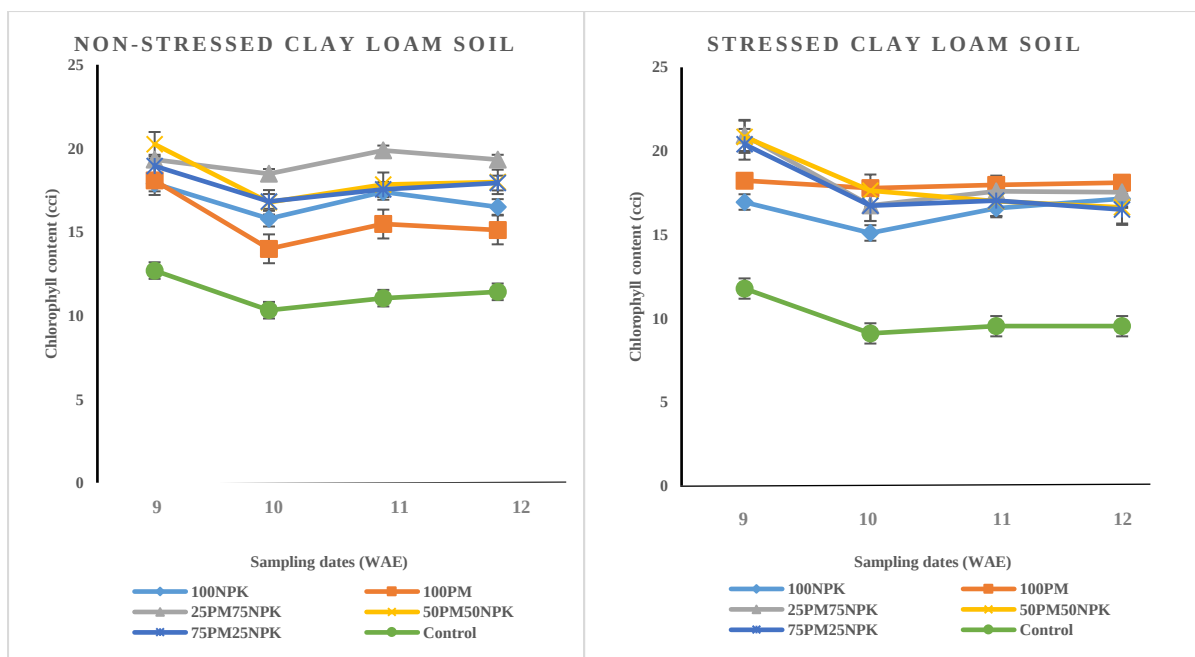


Figure 3.5: The chlorophyll content of okra leaves as affected by different fertilizer levels and moisture regimes

3.3.3 Main treatment effect on the Phenological attributes of okra plants

The results on the below Table 3.3 revealed that the initiation of flowers in okra plants took longer on the Clay loam soil than it took on the Sandy loam soil. The Clay loam soil also took longer to reach to 50% flowering than the Sandy loam soil took. Statistical analysis revealed that there was a significant difference ($p \leq 0.05$) between treatments on both the days to first flower initiation and to 50% flowering. Means with similar alphabet next to it do not differ significantly from each other.

Table 3.3: The effect of soil textural class on flowering of okra plants

Treatments		
Soil Type	Days to first flower initiation	Days to 50% flowering
Sandy loam	48.0b	55.2b
Clay loam	49.5a	60.3a
Significance ($p \leq 0.05$)	0.04	0.00

The results on the table 3.4 below reveal that initiation of flowers of okra plants was delayed by the moisture stress. The non-stressed plants gave their first flower before the stressed plants did. The moisture stress also delayed the plants to reach 50% flowering, as the non-stressed plants reached to 50% flowering before the stressed plants. Statistical analysis revealed that there was a significant difference ($p \leq 0.05$) between treatments on both the days to first flower initiation and to 50% flowering.

Table 3.4: The effect of moisture regime on the flowering of okra plants

Treatments	Days to first flower initiation	Days to 50% flowering
Moisture regime		
Non-stressed	47.4b	53.9b
Stressed	50.1a	61.6a
Significance ($p \leq 0.05$)	0.00	0.00

The results on the Table 3.5 below revealed that the fertilizers influenced the flowering of okra plants. The 75:25 PM and inorganic NPK fertilizer treatment gave the first flower initiation before all other treatments. It also reached to 50% flowering before all other treatments did. However, it did not differ statistically with the 100 PM on both days to first flower initiation and to 50% flowering. The control treatment was the last one to initiate first flower as well as reaching to 50% flowering. Statistical analysis revealed that there was significant difference ($p \leq 0.05$) between treatments on both the days to first flower initiation and to 50% flowering.

Table 3.5: The effect of Fertilizer combinations on the flowering of okra plants

Treatments	Days to first flower initiation	Days to 50% flowering
Fertilizer level		
Control	53.3a	68.0a
25PM/75NPK	50.8b	62.8b
50PM/50NPK	49.3bc	58.8bc
100 NPK	47.5cd	54.8cd
100 PM	46.3d	51.5d
75PM/25NPK	45.5d	50.8d
Significance ($p \leq 0.05$)	0.00	0.00

3.3.4 Treatment interaction effect on the phenological attributes of okra plants

The interaction effect of soil textural class and moisture regime is clearly recorded on the below Table 3.6. The non-stressed Sandy loam soil treatment initiated the first flower before the other treatments, followed by the non-stressed Clay loam soil treatment. A similar trend was observed on the days to 50% flowering. The stressed Clay loam soil was the last to initiate the first flower as well as reaching 50% flowering. Statistical analysis revealed that there was no significant difference ($p \leq 0.05$) between treatments on both the days to first flower initiation and to 50% flowering.

Table 3.6: The interaction effect of soil textural class and moisture regime on the flowering of okra

Treatments			
Soil type	Irrigation regime	Days to first flower initiation	Days to 50% flowering
Clay loam	Stressed	50.8a	64.7a
Sandy loam	Stressed	49.3ab	58.5b
Clay loam	Non-stressed	48.2bc	56.0b
Sandy loam	Non-stressed	46.7c	51.8c
Significance ($p \leq 0.05$)		0.01	0.03

The interaction effect of soil textural class and Fertilizer combinations is presented in Table 3.7 below. The interaction of Sandy loam soil and 75:25 PM and inorganic NPK fertilizer initiated the first flower before all the other treatments. The interaction of Sandy loam soil and 100 PM reached to 50% flowering before all the other treatments. However, it did not differ statistically with the interaction of Sandy loam soil and 75:25 PM and inorganic NPK fertilizer on the days to 50% flowering. The results revealed that the interaction of Sandy loam and fertilizers produced better results compared to the interaction of Clay loam soil and fertilizers. Statistical analysis revealed no significant difference ($p \leq 0.05$) between treatments.

Table 3.7: The interaction effect of soil textural class and Fertilizer combinations on the flowering of okra

Treatments			
Soil type	Fertilizer combinations	Days to first flower initiation	Days to 50% flowering
Clay loam	Control	53.5a	71.5a
Sandy loam	Control	53.0ab	64.5bc
Clay loam	25PM/75NPK	51.5abc	66.0ab
Clay loam	50PM/50NPK	50.0bcd	61.0bcd
Sandy loam	25PM/75NPK	50.0bcd	59.5cde
Clay loam	100 NPK	49.0cde	58.5cde
Sandy loam	50PM/50NPK	48.5cdef	56.5def
Clay loam	100 PM	47.0defg	53.5efg
Clay loam	75PM/25NPK	46.0efg	51.5fg
Sandy loam	100 NPK	46.0efg	51.0fg
Sandy loam	100 PM	45.5fg	49.5g
Sandy loam	75PM/25NPK	45.0g	50.0g
Significance ($p \leq 0.05$)		0.02	0.03

The interaction of no moisture stress ($>80\%$ FC) and 75:25 PM and inorganic NPK fertilizer initiated the first flower before all the other treatments (Table 3.8). However, it reached to 50% flowering on the same number of days as the interaction of no moisture stress with 100 PM and

100 NPK. The results reveal that the interaction of moisture stress and control treatment initiated it first flower after all the treatments, and it was the last to reach to 50% flowering. The results also revealed that the interaction of moisture stress treatment with 100 PM and 75:25 PM and inorganic NPK fertilizer initiated first flower and reached to 50% flowering before the non-stressed 50:50 PM and inorganic NPK fertilizer and 25:75 PM and inorganic NPK fertilizer. Statistical analysis revealed that there was a significant difference ($p \leq 0.05$) between treatment.

Table 3.8: The interaction effect of irrigation regime and Fertilizer combinations on the flowering of okra

Treatments			
Irrigation regime	Fertilizer combinations	Days to first flower initiation	Days to 50% flowering
Stressed	Control	54.5a	71.0a
Non-stressed	Control	52.0ab	65.0abc
Stressed	25PM/75NPK	52.0ab	68.0ab
Stressed	50PM/50NPK	50.5bc	63.5bcd
Stressed	100NPK	49.5bcd	60.5cd
Non-stressed	50PM/50NPK	49.5bcd	54.0ef
Non-stressed	25PM/75NPK	48.0cde	57.5de
Stressed	100PM	47.5cdef	54.0ef
Stressed	75PM/25NPK	46.5def	52.5ef
Non-stressed	100NPK	45.5ef	49.0f
Non-stressed	100PM	45.0ef	49.0f
Non-stressed	75PM/25NPK	44.5f	49.0f
Significance ($p \leq 0.05$)		0.02	0.05

3.4 Discussion

3.4.1 The effects of fertilizers on the growth parameters

Islam et al. (2017) reported that the highest number of leaves per plant, and plant height of tomatoes was obtained from the combination of organic and inorganic fertilizers at 2:3 and 1:3, respectively. The results obtained from this study concur with this finding as the most leaves were obtained mostly from the treatment with a combination of organic and inorganic fertilizers. The mixed fertilizer treatment was the best for okra growth and development, which could be interpreted as the release of nutrients from organic and inorganic fertilizers at different times. Also, Choudhary et al. (2015) concurred with the observation that the combination of organic and inorganic fertilizers improves plant height, leaf length, leaf width and number of leaves per plant.

According to Meena & Bhati (2016), the application of N, P and K whether alone or in combination revealed noticeable differences in the number of leaves per plant at 40 DAS. Uka

et al. (2013) reported that poultry manure produced maximum number of leaves per plant, while the control had the lowest, which was in line with preceding report (Okwuagwu et al., 2015). Tiarniyi et al. (2012) observed that the number of leaves of okra was greater in poultry manure treatment, they credited it to the obtainability of nutrients for easy preoccupation by the plant, therefore causing an increase in plant growth.

Comparatively, the high nitrogen content of poultry manure buttresses the vegetative growth of crops. Seyedbagheri (2017) observed a significant effect of organic manure on vegetative growth, grew faster from week 6 until the last day of growth parameters' data collection while plants supplied with NPK fertilizer grew quicker during the initial weeks of the experiment but eventually slowed down. This is in line with a study by Adewole and Ilesanmi (2012) in which it was proven that the application of inorganic fertilizers like NPK accelerate soil degradation resulted from the loss of organic matter which leads to elevated acidity levels, imbalance of nutrients and low crop yields. In addition, organic manures encourage microbial degradation and the gradual release of nutrients over time (Afe & Oluleye, 2017).

All the treatments with fertilizers produced a mean number of leaves higher than that of the control treatment. These results may have been influenced by the addition of nitrogen through application of poultry manure, NPK and Urea fertilizer combination. Nitrogen is the critical element that is responsible for vegetative growth in plants, and this nutrient is available in both the poultry and the NPK fertilizer (Afe & Oluleye, 2017; Meena & Bhati, 2016; Roca et al. 2018). The rate at which nitrogen is available in the soil or the rate at which plants absorb nitrogen from the soil has a huge impact on the vegetative growth of okra plants (Adekiya et al., 2019). Poultry manure application at 100% as well as a combination of 75% and 50% with NPK produced the highest mean number of leaves per plant on the no moisture stress treatment. This agrees with earlier findings by Adekiya et al. (2019) who reported that poultry manure produced the best leaf length compared to green manure and NPK separately at 60 DAS.

There are other nutrients such as P and K that are very crucial for the growth of food crops and maximizing production. Phosphorus, which is the second most limiting nutrient after nitrogen, is a vital component of ATP (adenosine triphosphate) which is the energy unit of plants formed during photosynthesis (Malhotra et al., 2018). Phosphorus is essential for the health and vigor of plants from the seedling stage to the adult or mature stage of the plant (Chan et al., 2021). Potassium is associated with the movement of water, nutrients and carbohydrates in plant tissues (Johnson et al., 2022). In addition, it is involved with enzyme activation within the plant, which affects protein, starch and ATP production (Ahammed et al., 2022). Potassium

has a major function in the induction of cell elongation and the maintenance of osmoregulation in plants by regulating the opening and closure of stomata, which affects how efficiently plants can utilize water for growth and development (Kumar et al., 2020). Hence the rapid okra plants growth observed relate to P and K availability from the various fertilizer combinations even under moisture stress conditions.

Number of leaves per plant, leaf length and leaf width are influenced by similar factors such as the availability of nitrogen, nitrites and phosphate content in the soil and the fertilizers applied (Meena & Bhati, 2016). Hence, that is why we observed the maximum number of leaves from the 75:25 PM and inorganic NPK fertilizer mix ratio treatment on the non-stressed plants, which according to these results, is the perfect combination which supplies adequate amounts of the afore mentioned minerals. The results reveal that treatments with more poultry manure had a greater improvement on the growth of okra plants. Organic manure is known of releasing nutrients at slow rate as compared to inorganic fertilizer, therefore, they are regarded as sustained sources of nutrients (Singh, 2012).

The number of leaves per plant did not constantly increase, instead they fluctuated from one week to the other. Several leaves were lost during the data collection period due to factors which include moisture stress, red spider mites and *Tuta absoluta*. The plants were infested by the red spider mites from the early stages of growth, and their effects on the growth started to be visible at a later stage. However, pesticides were introduced, and infestations were curbed. According to Warabieda (2015), the buildup of red spider mites under favorable conditions results in critical economical losses through the compromise of the vegetative growth and yield due to reduced transport of photosynthates. Park & Lee (2015) reported that the total leaf area was reduced by 14 and 20% at the medium and high mite infestation levels respectively. Similar reductions were observed in the total number of leaves per plant. However, the results revealed that the 75:25 PM and inorganic NPK fertilizer mix ratio treatment performed better than the other treatments under the spider mites' stress and produced the maximum number of leaves per plant.



Figure 3.6: Red spider mites and *Tuta absoluta* infestations

The measured number of leaves in an okra plant might be influenced by the presence of *Tuta absoluta* that resulted in drying and falling leaves from the plant. The symptoms of insect pest infection showed dry necrotic patches on leaves mostly from clay loam soil were first spotted at 5 WAE in few leaves from different treatments, which became pronounced at 9 WAE mainly from the 100% PM treatment. The infection was exacerbated by the attack of red spider mites. Biondi et al. (2018) reported that *Tuta absoluta* larvae feed voraciously on the leaves of okra plants, causing extensive damage and defoliation. This reduces the plant's ability to photosynthesize and negatively impacts its growth and development. The decline in the number of leaves infected by this insect pest disease is caused by the rapid falling of infected leaves. This disease gets hyper-active and causes more damage in warm and moist environment a combination prevalent in greenhouse condition (Johnson et al., 2014).

According to Attarde et al. (2012), high N levels encourage more vegetative growth in plants. Hence, the high N levels availed by the combination of both the organic and inorganic fertilizer increased the number of leaves per plant and the growth rate. These results agree with finding by Oladiran et al. (2018), who reported that the combination of inorganic fertilizer and poultry manure has been found effective in improving leaf health and overall plant development and vigor. Inorganic fertilizers have the nitrogen readily available to be absorbed and used by the plant whereas in organic manure the N must be broken down by microbes to be available for the plants (Sylvester et al., 2014). Combining inorganic fertilizer with poultry manure harness the benefits of both approaches. The inorganic fertilizer provides immediate nutrient availability for rapid growth, while poultry manure contributes to long-term soil health and

sustainable nutrient supply (Chintala et al., 2018). Hence, using a combination of organic and inorganic fertilizers can assist in supplementing the gap of each other.

Chemical fertilizers have high salt content that include nitrites, phosphate, potash among others that significantly increase plant growth and development (Ansari & Sukhraj, 2010). These salts from chemical fertilizers dissolve rapidly in the soil making themselves available to the plants as opposed to the nutrients in organic manure that need microbial activities to break and mineralize, thus takes time (Attarde et al., 2012). Organic fertilizers on the other hand continuously release nutrients to the soil for use by plants thereby keeping the soil fertile for longer periods and the plants healthier (Lewu & Mavengahama, 2010).

The chlorophyll content did not have a stable increase, it fluctuated from one week to the other. It would be high in the first week and low in the next, or vice versa. As mentioned above, the plants were infested with red spider mites which according to Murungi et al. (2014), penetrate the leaf surface causing a decline of in the chlorophyll content of the leaves leading to crop losses up to 90%. The authors also mentioned that the feeding habits of spider mites compromise the production of chlorophyll and photosynthesis by sucking the contents of the leaves.

Based on findings by Roca et al. (2018), N fertilizer application visibly increased both the plant height and leaf chlorophyll levels of young olive trees even under the stress of *Fusicladium oleagineum*. This agrees with the results of this study wherein the treatments with fertilizers produced higher chlorophyll levels than the control treatment under the stress by spider mites implying that improved fertilization management can assist in reducing the negative effects of plant disorders due to insect infestation. According to Ya-wei et al. (2019), N fertilizer is very critical for production and growth of plants which influences photosynthesis and chlorophyll fluorescence.

Ya-Wei et al. (2019) reported that low or reduced N levels markedly decreased chlorophyll content of two maize cultivars (ZH311 and XY508) at the seedling stage, and the degree of stress increased with time. These authors further reported that reduced N levels significantly affect the activity of photosynthesis, and the photo-protective mechanisms including the chlorophyll fluorescence of maize at the seedling stage. Negi et al. (2016) concluded that N deficiencies damage intracellular chloroplast structure and decrease chlorophyll content, making plants vulnerable to light injury.

Mir et al. (2015) conducted a study to assess the Effect of nano and biological fertilizers on carbohydrate and chlorophyll content of forage sorghum. They reported that manure and nano fertilizers had significant effect on chlorophyll and carotenoid. They also reported that the highest chlorophyll, carotenoid and carbohydrate were achieved from combining biofertilizers (phosphorbarvar) and chelated nano fertilizers (Fe) treatments application. These findings concur with the findings of the current study, which also revealed that the combination organic manure and chemical fertilizer improves the chlorophyll content of okra. Chlorophyll meter readings have been positively correlated with destructive chlorophyll measurements in wheat (Akhter et al., 2016), and have been a useful indicator for N top-dressing determination during plant vegetative period (Skudra & Ruza, 2017). Hence, the highest chlorophyll contents was observed from the treatments with fertilizers combinations, which may be related to N release at different times and rates by the organic manure and inorganic fertilizer used.

The *Tuta absoluta* on the clay loam soil did not have much influence in the chlorophyll content of leaves, except for those that were drying and falling due to infections. The fluctuation of the chlorophyll content may be due to the high temperatures and rapid moisture loss that were experienced by the plants due to the non-functioning of the wet wall. Roca et al. (2018) and Ya-wei et al. (2019) reported that fertilizers increase chlorophyll content plant leaves even under stress, especially with high nitrogen levels. Nitrogen deficiencies cause damage to the structure of intracellular chloroplast resulting to plants being vulnerable to light injury, hence decreasing chlorophyll content and photosynthesis (Negi et al., 2016). To supply plants with sufficient and consistent nitrogen, a combination of organic and inorganic fertilizers at the appropriate or optimum recommended rate is necessary. According to the results of this study, the 25%PM/75%NPK application rate of considered most appropriate to enhance chlorophyll production.

The results revealed that moisture stress compromises growth of okra in terms of mean number of leaves per plant and leaf chlorophyll content. Observations revealed prominent physiological responses including leaf wilting and curling, indicative of adaptive mechanisms to reduce transpirational water loss. Detailed measurements of chlorophyll content confirmed significant reductions compared to adequately watered controls, highlighting the direct impact of moisture stress on photosynthetic pigment synthesis. These results concur with findings by Falah & Yasir (2020), who reported that under conditions of reduced water availability, okra plants typically exhibit visible signs of stress such as leaf wilting and curling, indicative of adaptive responses to mitigate water loss through transpiration. Concurrently, moisture stress induces

chlorosis in leaves, resulting from diminished chlorophyll synthesis (Adejumo et al., 2018). Chlorophyll, essential for photosynthesis, declines under such conditions, impairing the plant's capacity to harness solar energy for carbohydrate production (Badr & Brüggemann, 2020). Additionally, stomatal closure, a regulatory response to conserve water, limits gas exchange necessary for optimal photosynthetic activity, further exacerbating the reduction in chlorophyll content and overall plant growth (Adejumo et al., 2018). These findings underscore the vulnerability of okra to moisture stress and emphasize the critical role of water management strategies in mitigating adverse effects on crop productivity and leaf physiology under conditions of environmental water deficit.

3.4.2 Main treatment effect on the phenological attributes of okra

The results revealed that the sandy loam soil significantly affected the number of days to first flower initiation and to 50% flowering, which may be due to the good drainage system in the sandy loam soil favouring the development of healthy plant roots. According to Van Wijk & Feddes (2020), proper drainage is crucial for the overall health and development of plants, and it plays a vital role in the flowering process. Adequate oxygen supply is essential for root respiration and nutrient uptake. Improved oxygen availability promotes healthy root development, leading to vigorous plants capable of producing abundant and vibrant flowers (Shukla & Srivastava, 2020). Proper soil drainage is essential for maintaining optimal conditions for plant growth, health, and flowering. It ensures that plants have access to the necessary resources, reduces stress, and minimizes the risk of diseases that could hinder the flowering process. It was also observed that the soil chemical analysis revealed that the sandy loam soil had higher available P level than the clay loam soil. According to Nasholm et al. (2009), sandy soils have lower pH, which can increase phosphorus solubility and availability. Phosphorus is essential for the general health and vigor of plants, leading to improved flower formation and seed production (Chan et al., 2021).

The results revealed that the no moisture stress treatment significantly enhanced the phenological attributes of okra. This may be because water is responsible for the transportation of nutrients from the roots to the entire plant parts, these may include nutrients required for flowering in plants. Lesk et al. (2021) argued that Moisture plays a crucial role in the flowering of plants, influencing various physiological processes that contribute to the development of flowers. The authors further mentioned that moisture is a key component in various biochemical processes, including photosynthesis and nutrient transport. Therefore, sufficient moisture ensures that plants have the necessary resources to support flower development.

Furthermore, moisture causes cell expansion which is responsible for the growth of floral organs such as petals and sepals. According to Dorji et al. (2020), Some plants use moisture conditions, among other factors, as signals for the appropriate time to initiate flowering. Adequate moisture can contribute to the synchronization of flowering with favorable environmental conditions. Moisture is a fundamental factor in the flowering process, influencing multiple aspects of plant physiology. Maintaining an appropriate balance of moisture in the soil and atmosphere is crucial for optimal flower development and reproductive success in plants.

The Fertilizer combinations significantly enhanced the phenological attributes of okra plants. These results may be due to their ability to supply most of the supplemental nutrient requirements for optimum production. According to Adhikari & Piya (2020), Each nutrient has a specific role in plant growth. Nitrogen is crucial for vegetative growth, phosphorus promotes flower and root development, and potassium supports overall plant health. Adequate nutrient availability may lead to robust flowering. Chan et al. (2021) reported that adequate phosphorus levels encourage the development of flower buds and enhance the initiation of flowering. Phosphorus is particularly important during the transition from vegetative to reproductive growth. It's crucial to note that while fertilizers are essential for plant health and flowering, excessive or imbalanced fertilization can have negative effects. Too much fertilizer, especially high nitrogen levels, may lead to nutrient imbalances, excessive vegetative growth, and delayed flowering (Islam et al., 2017). It's important to follow recommended fertilization practices based on soil tests, plant nutrient requirements, and specific crop needs.

3.4.3 Treatment interaction on the phenological attributes of okra plants

The interaction of sandy loam soil with no moisture stress significantly enhanced the phenological attributes of okra. These results may simply be due to the fact that proper soil drainage and adequate moisture availability promotes the growth and yield of plants. Proper soil moisture promotes microbes' activities and plant processes such as photosynthesis, leading to early and healthy flowering (Adekiya et al., 2019). The interaction of sandy loam soil with 75:25 PM and inorganic NPK fertilizer also enhanced the phenological attributes of okra with significance. The ability of organic manure and inorganic NPK fertilizer to release nutrients at different times and different rates maybe the cause of the observed results. The good drainage system of the sandy loam soil may have complimented the nutrients released by the poultry manure and inorganic fertilizer. The combination of good soil drainage and adequate fertilization leads to optimum agricultural productions (Akhter et al., 2019).

Similar results were observed from the interaction of no moisture stress and 75:25 PM and inorganic NPK fertilizer. The combination of good moisture levels and good Fertilizer combinations is an answer to many challenges in the crop production industry. Moisture availability ensures that essential nutrients from the fertilizer are accessible to the okra plants, this in turn, supports the development of flowers and reproductive structures. (Al-Ubaydi et al., 2017). Proper synchronization of fertilizer application with moisture availability is important. Applying fertilizer when there is sufficient moisture ensures that nutrients are absorbed by the roots, promoting optimal flowering (Erwin, 2006). Moisture stress can disrupt the uptake of nutrients, even if fertilizers are applied. Consistent moisture levels are essential for preventing stress and ensuring that the plant can utilize the nutrients efficiently for flowering (Uka et al., 2021). Balancing nutrient levels, ensuring proper timing of fertilizer application, and maintaining optimal moisture conditions contribute to healthy plants, robust flower development, and overall reproductive success (Islam et al., 2017). It's essential to consider the specific needs of okra, monitor soil moisture levels, and adjust fertilizer applications accordingly for optimal flowering and fruiting.

3.5 Conclusion

In conclusion, the combination of organic and inorganic fertilizers works best in improving the growth rate and phenological attributes of okra plants. The 75:25 PM-NPK mix ratio appears to be the best that can be considered for improving the overall plant growth under both the non-stressed and moisture stressed conditions, especially with the Barberton soil. The treatments with majority part of poultry manure 100% and 75% best improved the growth of okra plants than all other treatments on the moisture stress treatment. Therefore, it would be beneficial to use this fertilization method on a dry land production system. The availability of nutrients and moisture in the soil improves the rate at which the plants absorb both plants and nutrients, hence, improving the growth rate of the plant. Therefore, the balance between soil moisture and soil fertility must be maintained for optimum plant growth. However, excessive soil moisture promotes the spread of some diseases such as *Tuta absoluta*, therefore, it must be avoided. Lastly, for sustainability purposes and improving the soil structure, the use of organic manure is recommended.

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CHAPTER 4

Variation in soil amendments, moisture levels and soil textural types affect the yield attributes of okra

Abstract

A greenhouse trial was initiated to assess the combined effect of variable fertilizer mix ratios and soil moisture levels on the yield attributes of okra grown on two soils with distinct textural types. The factorial experiment was fitted into a nested design with 4 replications. The soil textural types (sandy loamy and clay loamy) and soil moisture regimes (<30% FC and >80% FC) constituted main and sub-plot, respectively while soil amendments comprising of the six fertilizer combinations constituted the sub-sub plots. The Fertilizer combinations included 100% poultry manure (PM) and 100% inorganic NPK fertilizer applied based on the recommended rates of 15t/ha and 100 kg/ha, respectively, and different mix ratios of PM and inorganic NPK fertilizers (75:25, 50:50, and 25:75). An unamended control treatment was included as standard check. Results revealed that integrated use of PM and NPK fertilizer at 75:25 mix ratio gave the best okra performance than other mix ratios, and therefore produced the best okra yield. The sandy loam soil gave a higher yield than from the Clay loam soil although no significant difference was recorded. The non-stressed treatment produced quantitatively higher yield than the stressed treatments. The interaction between soil textural types and Fertilizer combinations gave significantly highest fresh fruit weight (77.02 g/plant), mean number of flowers (4.56 per plant) and fruits (3.17 per plant), and fruit length (39.94 mm) and diameter (81.74 mm) recorded in clay loam soil under 75:25 mix ratio of PM and NPK fertilizer. Similarly, a significant interaction between soil moisture regime and Fertilizer combinations produced the highest fresh and dry fruit weights of 75.38 and 6.88 g/plant, respectively, mean number of flowers (4.50 per plant) and fruits (2.81 per plant), and fruit length (38.44 mm) and diameter (80.71 mm) in the non-stressed treatment with 75:25 PM and NPK fertilizer. The results of the study led to the rejection of the hypothesis that yield attributes will not differ across the main and interaction treatments.

Keywords: poultry manure, NPK fertilizer, okra yield, drought stress, soil texture

4.1 Introduction

Okra (*Abelmoschus esculentus*), also known as ladyfinger due to its shape, is an economically important vegetable crop that is widely grown in the tropical and sub-tropical regions. The crop is a source of valued nutrients as well as health benefits; and contains high minerals and

vitamins content that are key for proper maintenance of human health and prevent diseases such cancer, poor eyesight etc. (Afe & Oluleye, 2017). It is an important source of vitamin C, containing less calories and fat-free (Gemede et al., 2015). Reports abound on the potential of okra to reduce the chance of kidney problems particularly associated with blood sugar levels through frequent consumption (Santos et al., 2019; Meena & Bhati 2016; Gemede et al., 2015). Similarly, the consumption of okra has been reported to prevent and help against gastrointestinal problems (Gemede et al., 2014). Okra fruits are generally scarce in the South African retail markets with a very short lifespan and only available for a short period of time during cultivation.

Okra has a great potential as foreign exchange earner and reported to accounts for about 60% of the export of fresh vegetables from India to the Middle East and European countries (Singh et al., 2015). It is a crop that is often cross pollinated by insects such as honeybees (*Apis mellifera*) and bumblebees (*Bombus auricomus*). Adhikari and Piya (2020) revealed that more than 99% of okra cultivation is done exclusively in the developing countries of Asia and Africa with very poor productivity, especially in African countries compared with any other regions of the world. In South Africa, beside the fact that there is currently no large-scale cultivation of this important horticultural fruit crop, there is also very limited information on its fertilizer requirement to guarantee optimum yield and quality. This study investigated the potential practices that may increase crop yields, as well as increasing the availability of the crop with a moderate fertilizer input. Worse still, as a fresh produce, the fruit is also easily susceptible to rapid deterioration if not properly well stored after harvest. Therefore, the effect of different rates of chicken manure and NPK 2:3:2 (33) fertilizer, soil textural class and moisture regimes on the yield and quality of okra (*Abelmoschus esculentus*) was investigated on the crop using two soils with distinct characteristics. The null hypothesis for the study is that the yield and quality of okra will not differ across the soil textural types, soil amendments and irrigation levels, whereas the alternative hypothesis stated that there shall be a difference.

4.2 Materials and Methods

Detailed description of the methodology of the study and trial layout for the study are as previously provided in sections 3.2.1 to 3.2.4 in chapter 3.

4.2.1 Data collection

The measured parameters to address the study objectives included the number of flowers, number of fruits, length and diameter of fruits, and fruit fresh and dry weight. The number of

flowers and fruits were manually counted at 5 days interval beginning from 9 WAE until termination at 14 WAE. Fresh marketable fruits were harvested and weighed at 7 days regular interval from 10 WAE until the termination of the experiment while the cumulative fresh fruit weight was computed after termination of the experiment. The length and diameter of all harvested fresh fruits were measured using a ruler and a vernier caliper while fresh and dry fruit weights were measured on an electronic weighing balance. The total fresh fruit weight harvested per treatment was also computed at the end of the trial. Fruit dry matter yield was determined by placing the harvested fruits in brown envelopes and oven drying at 65 – 70°C until constant weight was obtained.

4.2.2 Statistical analysis

Data collected was subjected to normality and homogeneity tests using Sharpiro-Wilk test on Statistix-10. Statistical analysis of the repeated yield related data measured during the trial involved the use of Multifactorial ANOVA (MANOVA) model. The effect of Fertilizer combinations, moisture regimes and variation in soil textural types on the measured growth variables was analyzed based on the linear mathematical model:

$$Y_{ijk} = \mu + F_i + M_j + S_k + (F \times M)_{ijk} + (F \times S)_{ijk} + (M \times S)_{ijk} + (F \times M \times S)_{ijk} + E_{ijk},$$

where: Y_{ijk} = measured parameters, μ = population mean, F_i = Fertilizer combinations effect, M_j = Moisture effect, S_k = soil types effect, $(F \times M)_{ijk}$ = interaction effect of Fertilizer combinations and moisture regimes, and $(F \times S)_{ijk}$ = interaction effect of Fertilizer combinations and soil types. Others include $(M \times S)_{ijk}$ = interaction effect of moisture regimes and soil types, $(F \times M \times S)_{ijk}$ = interaction effect of Fertilizer combinations, moisture regimes and soil types, and E_{ijk} = random error effect. Test of significant difference between treatments mean was at 0.05 probability level while Tukey HSD was used for comparison of treatment means.

4.3 Results

4.3.1 Main treatment effect on the measured yield attributes of okra

Among the main treatment factors, only the variation in fertilizer combinations exerted significant ($p < 0.01$) effect on all measured yield attributes of okra while only the interaction between the variation in soil textural types and fertilizer combinations exerted a significant ($p < 0.05$) effect on fruit length and dry fruit weight (Table 4.1).

Table 4.1: p-values of MANOVA for the studied okra yield attributes

<i>Factor</i>	No. of flowers	No. of fruits	Fresh fruit weight	Dry fruit weight	Fruit length	Fruit diameter
Soil type (ST)	0.903	0.952	0.781	0.463	0.829	0.554
Moisture regime (MR)	0.614	0.827	0.537	0.684	0.602	0.569
Fertilizer level (FL)	0.002**	0.002**	0.000***	0.000***	0.001***	0.001***
ST*MR	0.778	0.520	0.124	0.150	0.812	0.735
ST*FL	0.179	0.242	0.104	0.014**	0.046*	0.059
MR*FL	0.262	0.249	0.443	0.580	0.650	0.788
ST*MR*FL	0.830	0.880	0.785	0.748	0.468	0.595
Significance at 5% = * significance at 1% = ** significance at 0.1% = ***						

Notwithstanding the non-significant ($p>0.05$) difference in the measured yield attributes from the two soil textural types used for the study, okra yield attributes measured in the sandy loam soil were quantitatively higher than from the clay loam soil while okra yield attributes measured in the non-stressed treatments were higher than from the stressed treatment (Table 4.2). The sole 100% PM treatment produced the best performance based on all assessed yield attributes except the number of fruits and fruit diameter, which were highest with the 75:25 PM and inorganic NPK fertilizer treatment (Table 4.2). However, the 75:25 PM and inorganic NPK fertilizer treatment produced the best results than all the other mix ratios for all measured yield components.

4.3.2 Treatment interaction effects on the yield components of okra

The result of the interaction between the different fertilizer combinations and variation in soil textural types revealed that the 75:25 mix ratio of PM and inorganic NPK fertilizer gave the highest measured okra yield attributes in both soil textural types (Table 4.3). The results show all highest measured yield attributes except dry fruit weight were obtained in clay loam soil amended with 75:25 mix ratio of PM and inorganic NPK fertilizer. However, the highest dry fruit weight was obtained though in clay loam soil but from the pot that received sole (100%) PM application.

Table 4.2: The effect of soil textural class, moisture regime and Fertilizer combinations on the yield attributes of okra

Factor	No. of flowers	Fresh fruit weight (g)	Dry fruit weight (g)	No. of fruits	Fruit length (cm)	Fruit diameter (mm)
<i>Soil type (ST)</i>						
Sandy loam	3.51a	50.77a	4.23a	2.05a	26.58a	54.16a
Clay loam	3.48a	49.40a	3.86a	2.04a	25.96a	50.81a
<i>Moisture regimes (MR)</i>						
Non-stressed ($\geq 80\%$ FC)	5.55a	51.62a	4.15a	4.07a	27.03a	54.10a
Stressed ($\leq 30\%$ FC)	3.43a	38.56a	3.95a	2.02a	22.52a	40.87a
<i>Fertilizer combinations (FL)</i>						
100PM	4.25a	72.02a	6.22a	2.63ab	37.16a	70.96a
75PM25NPK	4.22a	69.61a	5.81a	2.75a	33.66ab	71.25a
25PM75NPK	3.34b	48.41b	3.39b	2.01bc	25.00bc	50.00b
50PM50NPK	3.17b	41.03b	3.33b	1.76c	24.18bc	45.41b
100NPK	3.15b	35.14b	3.15b	1.63c	19.28c	39.56b
control	2.81b	34.32b	2.39b	1.50c	18.36c	37.72b

Means with the same letter within the same factor does not differ statistically from each other.

Table 4.3: Soil textural type x Fertilizer combinations interaction effect on okra yield components

Factor	No. of flowers	No. of fruits	Fresh fruit weight	Dry fruit weight	Fruit length	Fruit diameter
Clay loam*75PM25NPK	4.56a	3.17a	77.02a	6.12a	39.94a	81.74a
Clay loam*100PM	4.38a	2.63ab	73.76ab	6.65a	35.91ab	76.68a
Sandy loam*100PM	4.13ab	2.63ab	70.28ab	5.79a	34.38ab	65.24ab
Clay loam*100NPK	4.06abc	2.39abc	62.20abc	5.49ab	32.56ab	60.84ab
Sandy loam*75PM25NPK	3.88abc	2.32abcd	57.59abc	4.62abc	31.42abc	60.76ab
Sandy loam*25PM75NPK	3.18bcd	1.90bcd	50.37bcd	4.55abc	29.92abcd	58.58abc
Sandy loam*50PM50NPK	3.17bcd	1.88bcd	44.82cde	4.53abc	24.55bcde	47.10bcd
Sandy loam*100NPK	3.17bcd	1.70bcd	39.22cde	3.17bcd	21.80bcde	43.18bcd
Clay loam*25PM75NPK	3.13bcd	1.63cd	38.73cde	2.24cd	18.44cde	41.42bcd
Clay loam*50PM50NPK	3.00cd	1.63cd	31.69de	2.03d	17.44de	32.25cd
Clay loam*Control	2.63d	1.38d	29.90de	1.77d	14.92e	32.02cd
Sandy loam*Control	2.63d	1.31d	25.47e	1.60d	14.00e	29.99d

4.4 Discussion

4.4.1 Main treatment effect on yield and yield attributes

Notwithstanding the inconsequential effect of soil textural variation on the measured yield attributes, the sandy loam soil produced a quantitatively higher yield than the clay loam soil. This may be attributed to better drainage capacity of the sandy loam which possibly favored air flow and gaseous exchange in the plant roots. According to King et al. (2015), proper soil drainage can improve crop yields, reduce year-to-year yield variability, and provide trafficable conditions for field operations at critical times of planting or harvest. Good soil drainage ensures proper soil aeration and prevents waterlogging that can choke crops when not properly managed (Boico et al., 2022). Furthermore, the pre-planting soil test results revealed that the sandy loam had higher available P content than the clay loam, which may be a good explanation for these results. According to Yuan & Chen (2015), adding P promotes growth of the plant roots, resulting in better water and nutrients absorption that helps to promote improved plants' growth and yield. Phosphorus is a constituent of plant cells, essential for cell division and development of the growing tip of the plant (Alori et al., 2017). It is also essential for photosynthesis, which is a process of plants making their own food (Evans & Clarke, 2018), as well as improving flowering and seed production. Phosphorus deficiencies in the early growth stage of okra can be identified by stunted growth and fibre colors ranging from dark green to reddish purple caused by sugar accumulations, which negatively affect the seed and fruit development (Alori et al., 2017). The non significance between the soil type may be due to the exerted moisture stress and heat stress as the ventilation and wet wall was not functional. This may have led to an increase in the evapotranspiration process in the greenhouse. Non-functional wet wall implies the air in the greenhouse was drier and hence there was higher vapor pressure deficit that should lead to greater moisture deficit particularly in the stressed treatment.

The quantitatively higher yield obtained from the non-stressed treatment may be due to constant availability of moisture in the soil, which increases crop physiological processes such as photosynthesis and absorption of nutrients by the plant (Xiang et al., 2017). However, the difference was not significant possibly because the 15 days moisture stress period was inadequate to exert sufficient negative effect on the plants prior to receiving adequate moisture supply at $\geq 80\%$ FC. The presence of organic matter and/or clay content in the soil may also have contributed to the non-significant effect of the moisture conditions. The temperatures were very high during the experiment, and the wet wall and the fan were not functioning

properly, which may have also contributed to the non-significance observation. Unfortunately, the exponential growth of human population and industrial development have elevated water resources to the forefront of challenges facing modern society (Abdelkareem et al., 2018). Therefore, it is important to practice sustainable use of water resources in the crop production industries. In addition, drought also contributes to food scarcity and other challenges associated with the availability of water. Consequently, these challenges negatively affect crop production as they require certain amounts of water for optimum production (Anjum et al., 2017).

The reported decline in both the fresh and dry fruit weight in this study though agrees with earlier finding by Mathobo et al. (2017) who reported a typical unfavorable impact of water stress on crop plants including the reduction in fresh and dry biomass production. Eltigani et al. (2022) also mentioned that drought stress reduced shoot biomass of okra plants while Iqbal et al. (2020) reported that drought stress decreases the photosynthetic pigments, length of the plant, number of leaves and leaf area, resulting to reduced yield and biomass of the crop. However, unlike Mathobo et al (2017) that reported significant decline, the decline caused by moisture stress in the current study was not significant possibly because the stressed was kept only for 15 days. The reduction in yield capacity of the crop due to moisture stress according to Iqbal et al. (2020) is attributed to the reduction in water supply during the initiation of reproductive stage of okra tend to lead to overall yield reduction mainly as time of first picking approaches. Most morphological, physiological and biochemical processes associated with plant development are obstructed during drought stress thus resulting to poor photosynthesis, respiration, and overall crop yield (Chaturvedi et al., 2019). The disturbance of plant processes such as photosynthesis and respiration cause a markable decline in the growth rate, plant development and overall yield of plant crops.

Global food production relies on irrigation, especially in low rainfall areas such as South Africa. Early introduction of drought stress reduced leaf area, chlorophyll content, dry matter and yield in two common bean cultivars (D81083 and Sayyard), whereas post flowering drought stress resulted in a reduction in seed yield, pods per plant and 100 seed weight in small red seeded common bean, all due to the reduction of photosynthetic rate caused by stomatal conductance as a response to drought stress (Mathobo et al., 2017). This study has proven that soil amendments and the interaction of soil textural class and Fertilizer combinations have an influence in the yield attributes of okra.

As suggested by the results of this experiment, crop yield is believed to be dependent on four critical factors including soil fertility, availability of moisture, climate and diseases or pests (Gao et al., 2020; Rahman & Zhang, 2016). Therefore, to achieve high crop productivity, it is important to understand the impact of different fertilizer inputs on crop yields. Treatments with larger portion of poultry manure ($\geq 75\%$) in the mix ratio produced higher yield attributes than the sole inorganic NPK fertilizer in almost all measured parameters. According to Chung et al. (2021), poultry manure contains 13 essential plant nutrients, which when used as a fertilizer for okra may provide a portion or all of the plant's nutrient requirements (Afe & Oluleye, 2017).

Du et al. (2020) reported that Manure application significantly increased crop yield of grain by an average of 7.6% compared to mineral fertilizer across 774 comparisons in China. Adekiya et al. (2019) also find similar results with okra, where reported that mesquite leaves (organic fertilizer) produced the best yield in terms of tons per hectare (10.9) than the NPK (6.1) and control (3.9). The increase in the yield of plant crops by organic manure may be due to the significant increase of microbes (Choudhary et al., 2015), which improves the structure of the soil, decompose organic residues and release nutrients back into the soil for the crop (Majeed et al., 2018). Organic manure does not only supply plants with nutrients, but also improves the soil structure, soil microbes and moisture holding capacity (Afe & Oluleye, 2017). Due to the potential of organic manure to provide food to the soil microbes, it is therefore increasing the activities of microbes which in turn helps to convert unavailable plant nutrient to available form (Adhikari & Piya, 2020). Organic manure has also been found to sustain yield under continuous cropping and improve the fertility of a degraded soil (Uka et al., 2021).

The performance of the 75:25 PM and inorganic NPK fertilizer treatment agrees with findings by Miah et al. (2020), who recorded the highest number of flowers and fruits in integrated nutrient management treatment, whereas Vermi-Compost gave the lowest number of flowers and fruits at 56 days after sowing (DAS). Nutrients seemed more available to okra plants with the mixes than the inorganic fertilizer or organic manure alone. Similar result found that combine use of inorganic, organic and bio- fertilizers (Integrated Nutrient Management practices) not only improved the quality of fruit and soil health, but it can also produce better vegetative growth and yield of okra (Kumar et al., 2017). Application of a mix of organic materials and inorganic fertilizers can be used to sustain the production of okra in the tropics.

4.4.2 Treatment interaction effect on yield and yield attributes

The interaction between moisture regime and variable Fertilizer combinations with higher PM content in the mix ratio resulted in higher yields. These results may be due to the ability of poultry manure to release nutrient continuously (Singh, 2012), and the role played by moisture in the breaking down of poultry manure to release nutrients. According to Li et al. (2021), moisture content influences substance transformation during composting and the function of exogenous microbial agents. However, excessive water causes leaching, loss of nutrients and furthers contamination (Tang et al., 2023). Water is a good medium for dissolving and transporting metabolites and growth regulators in plants, which later promotes growth and yield of plants (Falah & Yasir, 2020).

The results revealed that the interaction of Sandy loam soil, fertilizers and no moisture stress result to higher numbers of flowers and fruits. This may possibly be attributed to application of fertilizers accelerated the development of inflorescence, which is positively correlated with the number of flowers and fruits in the following spring (Choudhary et al., 2015). Increased number of flowers might have also resulted because of increase in number of crowns per plant (Adekiya et al., 2019). Singh et al. (2015), also recorded the maximum number of flowers of strawberries from the in vermicompost + Azotobacter +PSB+AM (64.23) treated plants followed by vermicompost + PSB+AM (62.73), whereas the minimum in the control (45.28). In addition, lack of stress or supra-optimal levels of nutrients or saturating water levels can also impact progression towards flowering. Of these environmental cues, temperature and the presence of water, in particular, allow plants to synchronize flowering with the seasons (Erwin, 2006).

The higher yield is attributed to the higher number of flowers and fruits produced per plant. Increased foliage might have resulted in production of more photosynthates enhancing the yield potential (Du et al., 2020). As N is the chief constituent of protein, essential for protoplasm formation, which leads to cell enlargement, cell division and ultimately resulting in increased plant growth and fruit yield (Afe & Oluleye, 2017). The other reasons may be the additive effect of biofertilizers which might have provided better soil conditions inclusive of improved soil fertility, nitrogen fixation, phosphate solubilization, enhanced the efficacy of applied N and P; enhanced the activities of other microbes and also release of growth stimulants and many more. Efficacy of the inorganic fertilizer was pronounced when they are combined with biofertilizers (Choudhary et al., 2015).

The observation from the above results shows that there is a difference between the cumulative number of flowers and cumulative number of fruits from each treatment. This is evidence that there are flowers and fruits that did not get to their maturity or harvest stage. Several factors may have resulted to the loss of flowers or fruitlets, which includes the red spider mites which infested the plants; it may also be due to the hot weathers that existed during the term of the experiment. Hot weathers result to a massive loss of moisture by plant leaves and other parts of the plant (Mathobo et al., 2017). However, even after these losses, the interaction of Sandy loam soil, no moisture stress and fertilizer treatment still produced more fruits than the interaction with stressed treatments.

The results revealed that the interaction effect of Sandy loam soil, 75:25 PM and inorganic NPK fertilizer and no moisture stress was positive on the length and diameter of okra fruits. These results agree with findings by Akhter et al. (2019), who reported the application of 75% vermicompost (15 t/ha) and 25% inorganic fertilizer (Urea = 174 kg/ha, TSP = 150 kg/ha, MoP = 150 kg/ha, as recommended by Barc (2012)) to produce the best fruit diameter. Adhikari & Piya (2020) also reported that fruit diameter was significantly influenced by different sources of nutrient and the best fruit diameter was recorded from the poultry manure (2.13 cm), while the significantly minimum fruit diameter was recorded in control (1.97 cm). Adhikari & Piya (2020) who reported that the fruit length of okra was significantly influenced by the application of different nutrient sources, where the highest fruit length was found in poultry manure (19.94cm) which was statistically at par with chemical (19.23) and goat manure (18.81), and where the lowest fruit length was observed in control (14.64). Choudhary et al. (2015) reported that the highest fruit length of okra was observed from the combination of biofertilizers (Phosphate solubilizing bacteria; 5 kg/ha) and inorganic manure (N, P₂O₅ and K₂O; 150, 50 and 50 kg/ha respectively). Other scholars also agreed that a combination of organic and inorganic fertilizers enhance the fruit length of okra crops (Miah et al., 2020; Akhter et al., 2019; Adekiya et al., 2019).

These results reveal that the interaction treatments with more parts of poultry manure were more effective in increasing the fresh weight of okra fruits than the chemical fertilizer on the Clay loam soil. These results agree to findings by Adhikari & Piya (2020) who found poultry manure to produce higher yields (14.91 t/ha) than the chemical fertilizer (12.78 t/ha). Adekiya et al. (2019) also reported that higher yield response of crops due to organic manure application could be attributed to improved physical and biological properties of the soil resulting in better supply of nutrients to the plants.

The results revealed that the combination of 75:25 PM and inorganic NPK fertilizer produced the highest number of flowers and fruits of okra. These results agree with earlier findings reported by Attarde et al. (2012), who found that the highest number of okra flowers from a treatment with 75% vermicompost + 25% chemical fertilizer. Furthermore, drought stress at the initiation of flowering increases embryo abortion, while moisture stress at post flowering causes severe yield loss (Ali et al., 2022). Mathobo et al. (2017) also mentioned that the reduction in number of flowers per plant is much greater in dry beans when moisture stress was introduced during effective flowering stage as compared to the well irrigated treatment. These results are also supported by findings of Atijegbe et al. (2014), who recorded the highest number of fruits on 10t/ha poultry manure and recorded the least on the control treatment. He reported the 10t/ha poultry manure to do better than the 500kg/ha NPK fertilizer. It has also been reported that application of vermicompost and poultry manure subsequently increase yield attributing characters and yield of okra (Khandaker et al., 2017).

4.5 Conclusion

In conclusion, the Fertilizer combinations exerted a significant effect on all the measured yield attributes. The interaction of Fertilizer combinations with soil textural types exerted a significant effect only on the dry weight and fruit length of okra. The integrated use of poultry manure and inorganic NPK fertilizer at a ratio of 75:25 has proven to best improve the yielding of okra, under both the no moisture stress and moisture stressed treatments. Hence, it is recommended for farmers who are still struggling with farming capital and those who are still practicing dry land farming.

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CHAPTER 5

Application of variable inorganic fertilizer and poultry manure mix ratios under different soil textural types and moisture levels affect the post-storage quality attributes of okra

Abstract

A greenhouse trial was initiated to assess the combined effect of variable fertilizer mix ratios and soil moisture levels on the mineral quality attributes of okra grown on two soils with distinct textural types. The factorial experiment was fitted into a nested design with 4 replications. The soil textural types (sandy loamy and clay loamy) and soil moisture regimes (<30% FC and >80% FC) constituted main and sub-plot, respectively while soil amendments comprising of the six Fertilizer combinations constituted the sub-sub plots. The Fertilizer combinations included 100% poultry manure (PM) and 100% inorganic NPK fertilizer applied based on the recommended rates of 15t/ha and 100 kg/ha, respectively, and different mix ratios of PM and inorganic NPK fertilizers (75:25, 50:50, and 25:75). An unamended control treatment was included as standard check. Results revealed that integrated use of PM and NPK fertilizer at 75:25 mix ratio gave the best okra performance than other mix ratios in all the measured quality attributes of okra fruits. The sandy loam soil gave a higher quality than the clay loam soil in all measured quality attributes except the percent calcium and magnesium contents. The non-stressed treatment produced a quantitatively higher quality than the stressed treatment. Moisture stress reduces the ability of plants to absorb nutrients, which later affected the mineral quality of the okra fruits. The interaction effect of sandy loam soil with 75:25 PM and NPK fertilizer gave the highest performance in all the measured quality attributes. The interaction effect of non-stressed treatment and 75:25 PM and NPK fertilizer also gave the highest mineral quality attributes. The mineral quality attributes and weight loss of okra during storage period were significantly reduced after 21 days of storage. Higher quality loss was recorded in non-moisture stressed treatment than the moisture stressed treatments as well as its interaction with any of the mixed fertilizer ratios and/or soil textural classes. The results of the study led to the rejection of the hypothesis that mineral quality attributes will not differ across the main and interaction treatments. Similarly, the hypothesis that the mineral quality and fresh weight of okra will not be affected after 21 days of storage period was rejected.

Keywords: poultry manure, NPK fertilizer, mineral quality, drought stress, soil texture, shelf life, crop storage

5.1 Introduction

Okra is among the vital indigenous vegetable crops known for its mineral value and health benefits. A generally grown okra under normal conditions with no fertilizer application should give us the approximate nutrient content of 87.7% water, 2.2% protein, 0.3% fats, 7.9% carbohydrates, 1.6% fibre and 0.3% ash (Adewole & Ilesanmi, 2011). According to Santos et al. (2019), the mineral quality of the crop may be improved by applying organic poultry manure and seaweed. The oil content of the seeds can be as high as that of chicken eggs and soybeans. Mineral composition can affect the development of an okra plant; and subsequently have an effect on its overall mineral quality (Olaniyi et al., 2010). The Soil Fertility Commission of Minas and the Agronomic Institute of Campinas (2018) recommended doses ranging from 20 – 240 kg/ha of NPK 15:15:15 and 10 – 50 t/ha of organic fertilizer. Nevertheless, these rates often require review due to the existence of newly developed cultivars with better productive traits (Santos et al., 2019) and variation in soil and climatic conditions across different agro-ecological zones.

Among other benefits, okra consumption has been reported to exert a significant reduction in the risk of chronic diseases (Lengsfeld et al., 2004). These benefits are obtained from the presence of its antioxidant activities. The antioxidant properties found from antioxidant compounds in vegetables such as okra are associated with the presence of vitamin C and E, carotenoids, and bioactive compounds, mostly flavonoids (Gemedé et al., 2015). However, less information is available on the antioxidant capabilities of major bioactive compounds from an okra seed (Oyelade et al., 2003). Okra also has a high fibre, vitamin C, and folate content that help to promote human health (Ansari & Sukhraj, 2010). This study investigated the potential practices that may increase crop quality with a moderate fertilizer input. Worse still, as a fresh produce, the fruit is also easily susceptible to rapid deterioration if not properly well stored after harvest. Therefore, the effect of different rates of chicken manure and NPK 2:3:2 (33) fertilizer, soil textural class and moisture regimes on the internal and external quality of okra (*Abelmoschus esculentus*) was investigated on the crop using two soils with distinct characteristics. The study hypothesized that (i) the mineral and external quality of okra will not differ before and after storage across the soil textural types, soil amendments and irrigation levels, and (ii) the mineral composition of okra will not be affected by the storage method.

5.2 Materials and Methods

Detailed description of the methodology of the study and trial layout for the study are as previously provided in sections 3.2.1 to 3.2.4 in Chapter 3.

5.2.1 Data collection

The measured mineral quality parameters to address the study objectives included phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and iron (Fe). The samples were divided in to two, in which some were oven dried immediately after harvesting (before storage) while the other half were packaged into polyethylene bags and stored at room temperature for 21 days and thereafter oven dried (after storage). The mineral quality parameters were determined at the soil analysis laboratory at the ARC-Tropical and Subtropical Crops. Measured physical quality parameters included moisture loss by weighing at 7 days intervals from the day of storage using electronic weighing balance, and daily visual observation of the fruits for possible appearance of black spots and molds.

5.2.2 Statistical analysis

Detailed description of the statistical analysis of the study is as previously provided in section 4.2.2 in Chapter 4.

5.3 Results

5.3.1 Main treatment effect on the measured mineral quality attributes of okra

Among the main treatment factors, the soil textural types exerted significant effect ($p < 0.05$) in all the measured quality attributes. The moisture regime factor did not have a significant effect ($p \geq 0.05$) in any of the measured quality attributes. The variation in Fertilizer combinations also exerted significant effect ($p < 0.05$) on all measured quality attributes of okra (Table 5.1). Similarly, the interaction between variation in soil types and Fertilizer combinations exerted significant ($p < 0.05$) effect in all measured quality attributes. The interaction between variation in soil type and moisture regime, and between moisture regime and Fertilizer combinations only exerted a significant effect in P and Mg quality attributes.

Table 5.1: p-values of ANOVA for the studied okra mineral quality attributes

Factors	P %	K %	Ca %	Mg %	Fe mg/kg
Soil type (ST)	0.000***	0.030*	0.041*	0.035*	0.013**
Moisture regime (MR)	0.106	0.081	0.203	0.591	0.326
Fertilizer level (FL)	0.000***	0.003**	0.021*	0.004**	0.000***
ST*MR	0.049*	0.091	0.130	0.019**	0.059
ST*FL	0.032*	0.013**	0.041*	0.043*	0.024*
MR*FL	0.025*	0.056	0.059	0.041*	0.063
ST*MR*FL	0.132	0.601	0.103	0.064	0.320

*, ** & *** implies significance at 5%, 1% and 0.1%, respectively; ST, MR and FL implies soil type, moisture regime and fertilizer level, respectively.

Okra quality attributes measured in the clay loam soil were significantly higher than from the sandy loam soil except the P and Fe, where the sandy loam soil produced significantly higher attributes. Notwithstanding the non-significant ($p>0.05$) difference in the measured quality attributes from the two moisture regimes used for the study, okra quality attributes measured in the non-stressed treatments were higher than from the stressed treatments (Table 5.2).

Table 5.2: The effect of soil textural class, moisture regime and Fertilizer combinations on the mineral quality attributes of okra

Factor	P %	K %	Ca %	Mg %	Fe mg/kg
Soil type (ST)					
Sandy loam	0.91a	2.04b	0.59b	0.54b	45.08a
Clay loam	0.51b	3.84a	0.88a	1.48a	38.75b
Fertilizer combinations (FL)					
100PM	0.58ab	2.67ab	0.78ab	0.61ab	44.75ab
75PM25NPK	1.57a	3.83a	1.78a	1.58a	59.50a
25PM75NPK	0.65ab	2.20ab	0.77ab	0.56ab	39.00ab
50PM50NPK	0.57ab	2.60ab	0.71ab	0.55ab	38.25ab
100NPK	0.56ab	2.56ab	0.71ab	0.53b	37.75ab
control	0.32b	2.36b	0.67b	0.53b	37.25a

Means with the same letter within the same factor do not differ statistically from each other.

The 75:25 PM and inorganic NPK fertilizer combination treatment produced significantly higher quality attributes than all the other mix ratio treatments including the sole (100%) PM and NPK treatments.

5.3.2 Treatment interaction effects on the mineral quality components of okra

The measured concentration of P and Mg in okra fruit was significantly highest in non-moisture stress sandy loam soil and non-moisture clay loam soil, respectively (Figure 5.1). The measured Mg content in the okra fruits obtained from non-moisture stress clay loam is statistically comparable to the content obtained from non-moisture stress sandy loam soil. Notwithstanding the non-significant moisture stress and soil textural type interaction effect on K, Ca and Fe, quantitatively higher Fe was recorded in sandy loam soil with non-moisture stress interaction treatment while the clay loam soil with non-moisture stress plants produced quantitatively highest K (0.84%) and Ca (1.21%) content. Among the various soil moisture conditions and fertilizer combinations, the non-moisture stress treatment with a combination of 75:25 PM and inorganic NPK fertilizer produced significantly highest P and Mg content (Table 5.3). The results revealed that the interaction between soil textural types and Fertilizer combinations produced the highest values for all the measured mineral quality attributes recorded in sandy loam soil amended with 75:25 mix ratio of PM and inorganic NPK fertilizer (Table 5.4). The interaction of clay loam soil with control produced a significantly lower quality in all the measured mineral quality attributes. However, it was significantly comparable to the interaction of sandy loam soil with control on Ca, Mg and Fe.

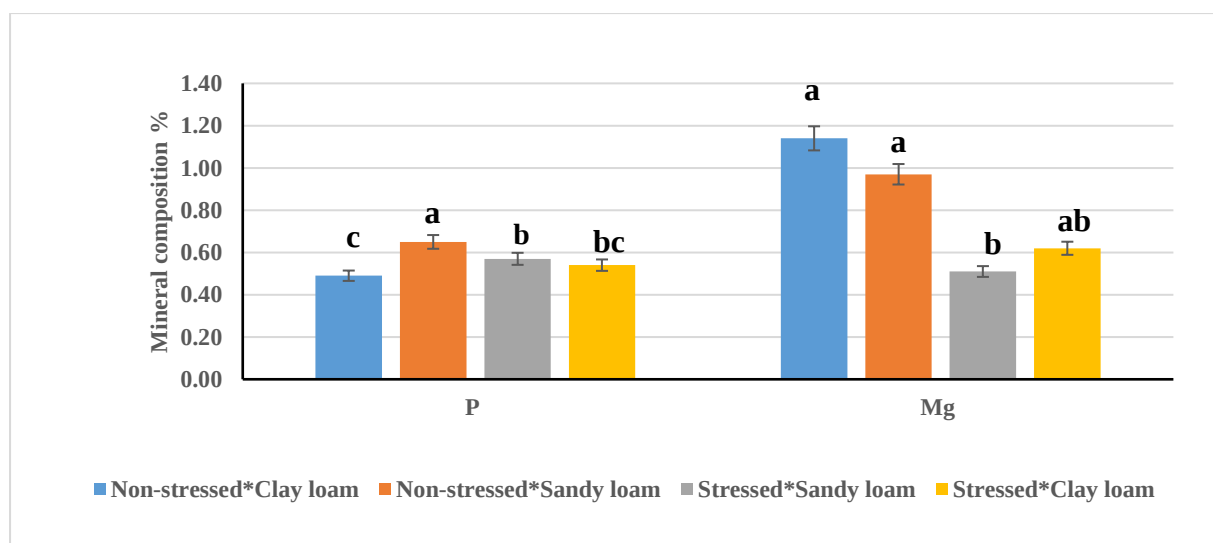


Figure 5.1: Moisture regime x soil textural type interaction effect on okra mineral quality components

Table 5.3: Moisture regime x Fertilizer combinations interaction effect on the mineral quality components of okra

Treatment combinations	P%	Mg%
Non-stressed*75PM25NPK	0.71a	0.76a
Non-stressed*100PM	0.61ab	0.59ab
Non-stressed*25PM75NPK	0.57ab	0.59ab
Non-stressed*100NPK	0.60ab	0.54ab
Non-stressed*Control	0.45b	0.49b
Non-stressed*50PM50NPK	0.61ab	0.64ab
Stressed*50PM50NPK	0.54ab	0.57ab
Stressed*25PM75NPK	0.56ab	0.57ab
Stressed*100NPK	0.53ab	0.53ab
Stressed*75PM25NPK	0.56ab	0.56ab
Stressed*100PM	0.57ab	0.53ab
Stressed*Control	0.38bc	0.41bc

Table 5.4: Soil textural type x Fertilizer combinations interaction effect on the mineral quality components of okra

Treatment combinations	P %	K %	Ca %	Mg %	Fe mg/kg
Sandy loam*100% PM	0.65ab	2.96ab	0.80ab	0.58b	48.50ab
Sandy loam*100% NPK	0.63ab	3.17ab	0.78abc	0.57bc	44.00ab
Sandy loam*75PM/25NPK	1.60a	3.67a	1.76a	1.56a	57.00a
Sandy loam*50PM/50NPK	0.60abc	2.71ab	0.74bc	0.54bc	39.50ab
Sandy loam*25PM/75NPK	0.59abcd	2.60ab	0.64bc	0.51bc	41.00ab
Sandy loam*control	0.50de	2.39b	0.60c	0.50bc	36.50b
Clay loam*100% PM	0.54bcde	2.49b	0.80ab	0.59b	43.00ab
Clay loam*100% NPK	0.53cde	2.45b	0.77abc	0.58bc	41.00ab
Clay loam*75PM/25NPK	0.52cde	2.37b	0.76abc	0.56bc	40.00ab
Clay loam*50PM/50NPK	0.50de	2.61ab	0.96ab	0.70ab	41.00ab
Clay loam*25PM/75NPK	0.50de	2.36b	0.65bc	0.53bc	41.00ab
Clay loam*control	0.49e	2.34b	0.58c	0.50bc	36.00b

Means with the same letter within the same factor do not differ statistically from each other.

5.3.3 Effect of storage on the mineral quality attributes of okra

5.3.3.1 Main treatment effect on the mineral quality of okra

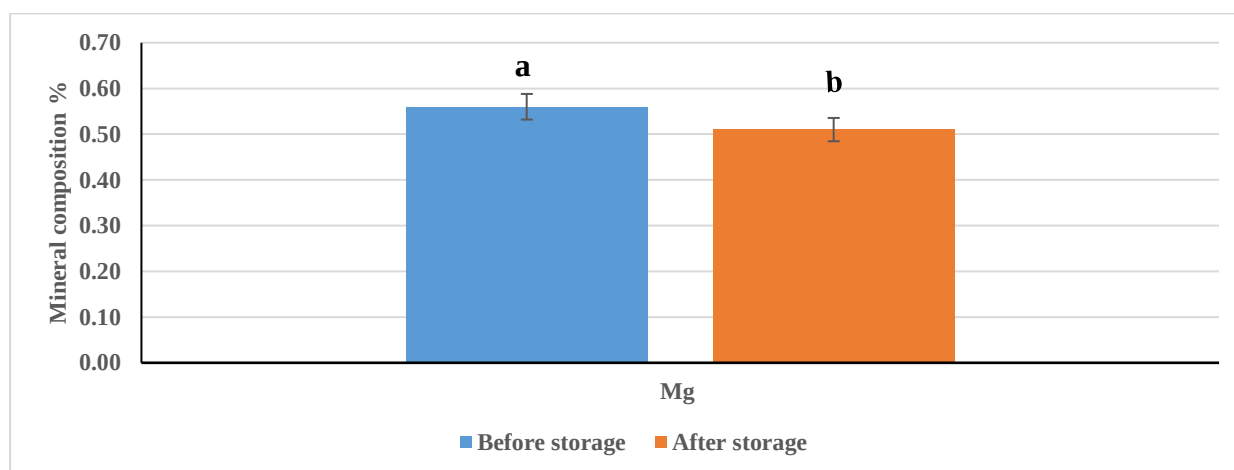
Neither the length of storage nor the variation in soil textural types exerted any significant effect on the selected mineral quality attributes but the content of Mg was significantly ($p=0.000$) affected by the length of storage (Table 5.5). However, the interaction between storage length with fertilizer combinations had a significant effect on the K and Mg quality attributes of the crop.

Table 5.5: p-values of ANOVA for the studied okra mineral quality attributes

<i>Factors</i>	P%	K%	Ca%	Mg%	Fe mg/kg
Length of storage (SL)	0.580	0.061	0.072	0.000***	0.478
SL*ST	0.491	0.594	0.305	0.002**	0.117
SL*MR	0.277	0.613	0.483	0.135	0.919
SL*FL	0.446	0.034*	0.879	0.028*	0.642
SL*ST*MR	0.167	0.208	0.433	0.348	0.967
SL*ST*FL	0.685	0.373	0.260	0.086	0.433
SL*MR*FL	0.810	0.563	0.264	0.067	0.345

*, ** & *** implies significance at 5%, 1% and 0.1%, respectively; ST, MR and FL implies soil type, moisture regime and fertilizer level, respectively.

Notwithstanding the non-significant effect of the storage period on the selected quality attributes, fruits dried prior to storage had significantly higher Mg contents than the fruits that fruits stored for 21 days before drying (Table 5.5 & Figure 5.2).

**Figure 5.2:** Storage effect on okra mineral quality components

5.3.3.2 Treatment interaction effect on the mineral quality of okra

The interaction effect between storage types and soil textural types exerted a significant effect on the measured Mg content of okra (Figure 5.3). The interaction of no storage and sandy loam soil produced a significantly higher Mg component. The interaction of storage and sandy loam soil had a significant effect on the Mg of okra, and therefore produced the lowest Mg. The interaction of storage with moisture regime did not have a significant effect on the mineral quality of okra.

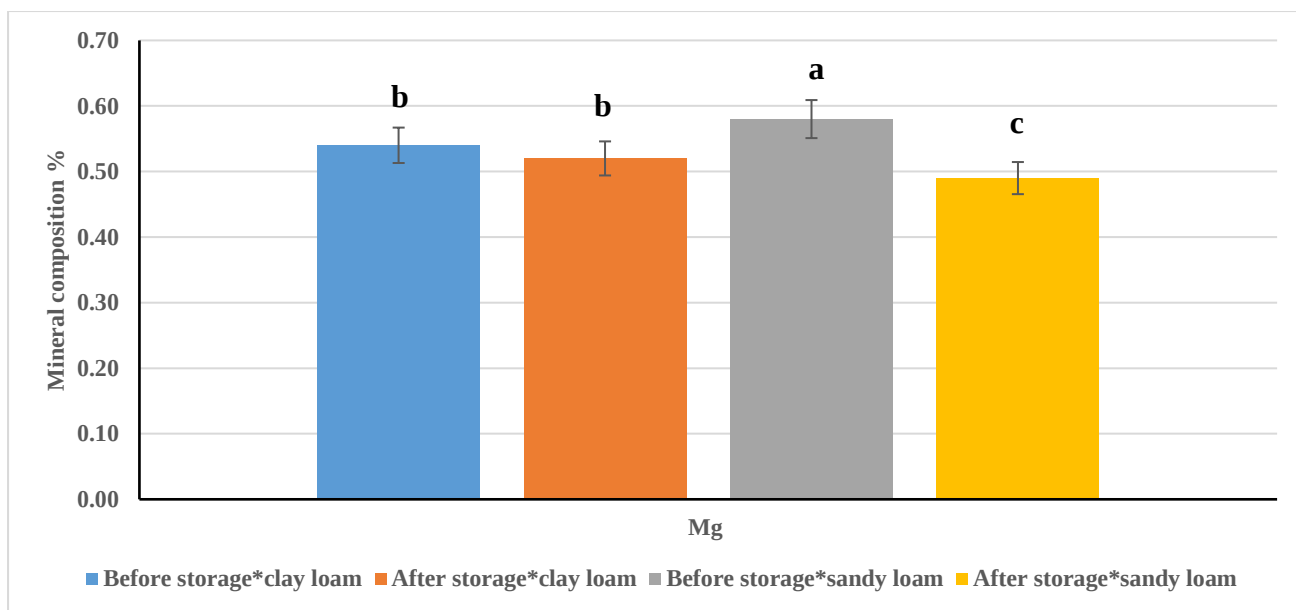


Figure 5.3: Storage x soil textural type interaction effect on okra mineral quality components

However, the interaction of length of storage with non-stressed plants produced a quantitatively higher mineral quality composition. The interaction between length of storage and any of the fertilizer combinations had a significant effect on the on the K and Mg of okra (Table 5.5 & 5.6). Fruits from the 75:25 PM and inorganic NPK fertilizer treatment before storage produced the highest K content while the 50:50 PM and inorganic NPK fertilizer treatment before storage had the highest Mg content.

Table 5.6: Storage x Fertilizer combinations interaction effect on the mineral quality components of okra

Factor	K%	Mg%
<i>Storage*Fertilizer level (MR*FL)</i>		
Before storage*75PM/25NPK	3.00a	0.54bc
After storage*75PM/25NPK	2.36e	0.53cde
Before storage*50PM/50NPK	2.75abcd	0.60a
After storage*50PM/50NPK	2.60cde	0.49ef
Before storage*100PM	2.96ab	0.56bc
After storage*100PM	2.67abcde	0.50def
Before storage*100NPK	2.83abc	0.53cd
After storage*100NPK	2.48de	0.48f
Before storage*25PM/75NPK	2.64bcde	0.55bc
After storage*25PM/75NPK	2.56cde	0.48f
Before storage*control	2.52cde	0.58ab
After storage*control	2.49cde	0.55bc

5.3.4 Main and treatment interaction effect on the fresh weight of okra fruits during storage

A significant ($p \leq 0.05$) variation in the fruit moisture content of the fresh weight of okra during the first 14 days of storage (Table 5.7). The interaction between moisture regime and soil type at 7 days during storage as well as soil type and Fertilizer combinations at day 1 and 7 during storage exerted a significant effect on the fresh weight loss of okra. A 3-way ANOVA between soil textural type, moisture regime and variation in Fertilizer combinations exerted a significant effect on the fresh weight of okra at 7 days of storage.

Table 5.7: p-values of ANOVA for the weight loss of okra during storage period

<i>Factors</i>	Day 1	Day 7	Day 14	Day 21
<i>Moisture regime (MR)</i>	0.029*	0.013**	0.042*	0.051
<i>ST*MR</i>	0.051	0.039*	0.055	0.092
<i>MR*FL</i>	0.048*	0.026*	0.051	0.065
<i>ST*MR*FL</i>	0.053	0.049*	0.054	0.109

*, ** & *** implies significance at 5%, 1% and 0.1%, respectively

Fruits harvested from the non-stressed plants recorded higher fresh weights than those from the stressed plants across the sampling dates (Figure 5.4). Fruits harvested from the non-stressed treatment lost moisture and shrank quicker than those harvested from the stressed treatment. Molds appeared on some of the fruits harvested from the non-stressed treatment at day 16 of storage (Figure 5.5) while there were no molds on the fruits harvested from the moisture stress treatment over the 21 days. Moisture loss was rapid during the first 7 days of storage on the non-stressed treatment.

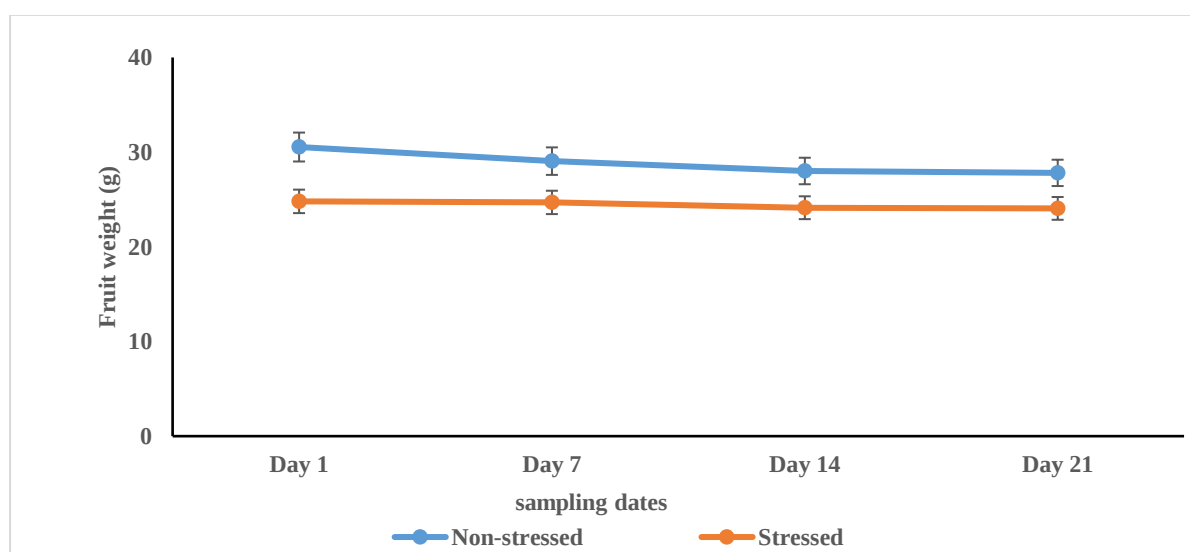


Figure 5.4: Effect of soil moisture regime on fresh fruit moisture loss during storage



Figure 5.5: Fruits from the no moisture stress treatment at day 16 of storage

5.3.5 Treatment interaction treatment effect on the weight loss of okra fruits during storage

The interaction of no moisture stress with clay loam soil produced the heaviest fruit weight during the 21 days of storage, except the first day, where the heaviest weight was produced by the interaction of no moisture stress with sandy loam soil. The interaction of no moisture stress with clay loam soil gave a significantly heavier weight at day 7 of storage (Figure 5.6). However, fruits from the interaction of no moisture stress and sandy loam soil lost moisture and shrank quicker than other treatments. Fruits from the interaction of moisture stress and clay loam soil lost moisture at a very low and constant rate. The interaction of no moisture stress with any of the Fertilizer combinations treatment had a very rapid moisture loss during the first 7 days of storage (Table 5.8). Whereas the interaction of moisture stress with any of the Fertilizer combinations treatment had a low and constant moisture loss throughout the storage period. The massive moisture loss on the no moisture stress treatments interaction resulted to a shrink and loss of external quality on the fruits.

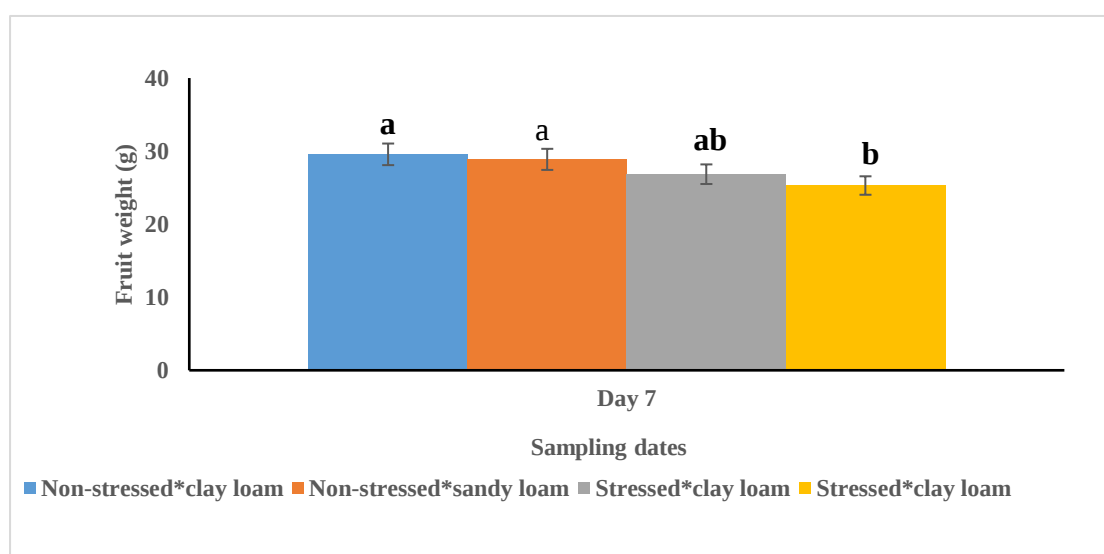


Figure 5.6: Moisture regime x soil type interaction effect on moisture loss of okra fruits

Table 5.8: Moisture regime x Fertilizer combinations interaction effect on the weight loss (g) of okra

Treatment	Day 1	Day 7
Non-stressed*75PM/25NPK	40.13a	35.99a
Non-stressed*100PM	37.07ab	32.13ab
Non-stressed*50PM/50NPK	36.84ab	31.96ab
Non-stressed*100NPK	33.50ab	27.66b
Non-stressed*25PM/75NPK	33.25ab	27.14b
Stressed*100PM	31.81ab	29.87b
Non-stressed*control	31.58ab	26.87b
Stressed*100NPK	28.90ab	27.19b
Stressed*50PM/50NPK	27.51ab	26.68b
Stressed*75PM/25NPK	27.20ab	26.25b
Stressed*25PM/75NPK	25.24ab	24.67b
Stressed*control	23.86ab	23.06b

5.4 Discussion

5.4.1 Main treatment effect on mineral quality

The results have shown that the clay loam soil produced the highest Ca, K and Mg than the sandy loam soil, this may be due to the initially higher macro nutrients content in the clay loam soil than it was in the sandy loam soil. Likewise, the sandy loam soil had a higher initial phosphorus content, it has therefore produced a higher phosphorus content than the clay loam soil. These results agree with Adekiya et al. (2020), who reported that the mineral composition of okra is directly influenced by the availability of minerals in the soil. Different soil textures can impact the concentrations of essential minerals such as calcium, potassium, magnesium, and others in the okra plants.

The quantitatively higher yield obtained from the non-stressed treatment may be due to constant availability of moisture in the soil, which ensures a steady supply of water to the okra plants, facilitating the uptake of essential minerals from the soil (Xiang et al., 2017). According to Anjum et al. (2017), inadequate irrigation can lead to water stress in okra plants, affecting their ability to take up minerals from the soil. This stress can lead to reduced mineral content in the

harvested okra. Whereas proper irrigation practices contribute to an even distribution of water and nutrients in the soil. This helps ensure a balanced uptake of essential minerals, promoting uniform growth and mineral quality in okra. Lastly, proper irrigation management is crucial for optimizing the mineral quality of okra. Balancing water supply, avoiding water stress, and considering water quality are essential factors that contribute to the overall health and mineral content of okra plants. Regular monitoring of soil moisture levels and adjusting irrigation practices accordingly can help promote the desired mineral quality in harvested okra (Iqbal et al., 2020).

The best performance on the selected quality attributes was recorded from the integrated use of poultry manure and inorganic NPK fertilizer at a rate of 75:25 respectively. These results may be due to that the integrated use of poultry manure and inorganic NPK fertilizer providing nutrients to the plants at a rapid rate and for a long period of time. These results agree to findings by Miah et al. (2020), who found the integrated use of poultry manure and NPK fertilizer to have a synergistic effect on the mineral composition of okra. They further mentioned that organic and inorganic fertilizers contribute different nutrients and improve soil structure, fostering optimal conditions for plant growth. According to Kumar et al. (2017), the combination of poultry manure and NPK fertilizer provides a balanced and comprehensive nutrient supply. This helps avoid nutrient imbalances and deficiencies, promoting optimal mineral composition in okra.

5.4.2 Treatment interaction effect on mineral quality

The results revealed that the interaction of no moisture stress with sandy loam soil produced an overall higher quality. These results may be due to that this interaction provided a conducive environment for the plants by the good drainage system of this soil type which allows for improved aeration, nutrient exchange and microbial activities (Azuka & Idu, 2022). It may also be due to the ability of moisture to transport minerals and nutrient from the soil to the plant (Chaturvedi et al., 2019). The properties of these two factors may have a good influence in the quality of okra fruits. According to Fatin et al. (2020), the combination of good soil drainage and optimum irrigation practices is crucial for promoting healthy root development, nutrient uptake, disease prevention, and ultimately, enhancing the quality and yield of okra. Well-drained soil and optimal irrigation contribute to the resilience of okra plants against environmental stresses such as drought or heavy rainfall. This resilience can positively impact the overall quality of the crop.

The interaction between moisture regime and variable Fertilizer combinations with higher PM content in the mix ratio resulted in higher quality. These results may be due to the ability of poultry manure to release nutrient continuously (Singh, 2012), and the role played by moisture in the breaking down of poultry manure to release nutrients. According to Li et al. (2021), moisture content influences substance transformation during composting and the function of exogenous microbial agents. However, excessive water causes leaching, loss of nutrients and furthers contamination (Tang et al., 2023). Water is a good medium for dissolving and transporting metabolites and growth regulators in plants, which later promotes growth, yield and quality of plants (Falah & Yasir, 2020).

The results revealed that the interaction of sandy loam soil with the 75:25 PM and inorganic NPK fertilizer significantly affected the mineral composition of okra. The good drainage system of sandy loam soil, and the ability of poultry manure to provide constant supply of nutrients may be reason for these results. The chemical composition of the poultry manure revealed that it contained high amounts of these nutrients, which may have also influenced the results of this study. According to Meena & Bhati (2016), fertilizer application improves both the yield and mineral quality of an okra crop. Santos et al. (2019) reported that the combination of organic and inorganic fertilizers to okra produces the best number of fruits, growth and mineral composition of the crop. The improved nutrient availability from both poultry manure and NPK fertilizer can contribute to better fruit quality parameters, which include such factors as size, color, taste, and mineral content of the okra pods (Adekiya et al., 2020).

5.4.3 Effects of storage on the mineral quality of okra

The observed decrease in Mg content of okra fruit during storage is possibly attributed to the solubility of magnesium ions in water, which were subsequently lost from the fruits through evaporation loss and other processes. This agrees with Xie et al. (2021) who reported that as water is lost, soluble magnesium compounds may leach out of the fruit leading to a decrease in magnesium levels. It's crucial to note that the effects of storage on okra quality depend on various factors, including initial quality, storage conditions, and duration. Adhering to proper post-harvest handling practices, maintaining optimal storage conditions, and monitoring the vegetable regularly are essential for preserving the quality of okra during storage. In this study, the fruits were packaged on polyethene bags and stored at room temperature. I observed that the fruits that were dried immediately after harvest had higher quality composition than those that were stored for 21 days before drying. The mineral composition of okra can be influenced

by the duration and conditions of storage. While minerals are generally stable compounds, storage conditions and duration can affect the overall mineral quality of okra (Alshimaa et al., 2021). Based on findings by Rani et al. (2021), prolonged storage may lead to a gradual loss of some minerals, particularly if storage conditions are not optimal. Exposure to factors such as light, air, and fluctuating temperatures might contribute to mineral degradation over time.

5.4.4 Effects of storage on the external quality of okra

The results of the study revealed that moisture significantly affected the shelf life of okra in terms of external quality. These results may be due to the fact that the fruits from no moisture stress had higher contents of moisture which promotes enzyme activities. According to Xanthopoulos et al. (2017), post-harvest losses caused by the loss of moisture result to visual degradation, firmness loss and loss of succulence due to shrinking, which are associated with marketable loss. The rate at which fresh vegetables lose moisture needs to be controlled in order to extend their shelf life. Water is the main constituent of fresh vegetables like okra which maintains the freshness of the produce by maintaining the turgidity of the cells (Khan et al., 2016).

Harvested produce should be handled cautiously to minimize both water loss and the presence of free water. This study showed that moisture loss resulted to weight loss, wilting and shriveling with free water or condensation facilitated pathogen growth. Understanding and managing water relations is therefore a critical component of postharvest handling, second only to temperature management. At the time of harvest the moisture content of okra was very high with a fresh appearance and crisp texture. Harvesting removed the plant part from its water supply and the product began to lose weight. This loss of water compromised the outside appearance of the fruits, leading to a loss of market value as well as reducing its saleable weight. Consequently, reducing water loss might improve produce appearance, quality, shelf life and profitability. During postharvest handling and storage, fresh vegetables lose moisture through their skins via the transpiration process (Ma et al., 2017).

The study revealed a significant soil moisture level and soil textural type interaction effect as well as soil moisture level and fertilizer interaction on the fruits post-harvest moisture loss. Although there is a dearth of information on the interaction effect of variation in soil textural type and moisture regime on the shelf life of okra, Gardas et al. (2018) emphasized the importance of proper soil and moisture management for post-harvest handling and maximizing the shelf life of vegetable crops. The implication of a slower moisture loss in fruits from sandy

loam than the clay loam soil is that regular monitoring and adjustment of irrigation under clayey soil is critical to optimizing postharvest storage conditions and extending the shelf-life of okra. Hence, optimal moisture balance in soils with variable texture may support consistent moisture levels thus improving shelf life of fresh vegetables. According to Adekiya et al. (2020), sandy soils are excessively drained and often lead to dehydration while clayey soils can cause waterlogged conditions with both extremes potentially impacting on the shelf life of vegetables. Conversely, high soil moisture level can lead to increase microbial activity potentially accelerating the decay of vegetables and reducing their shelf life (Al-Tayyar et al., 2020) which possibly explains the reduced shelf life observed in fruits from the non-moisture stress treatment. Earlier study by Casals et al. (2021) revealed that the interaction between irrigation levels and fertilizer combinations indirectly influenced the shelf life of tomato by affecting its growth, physiology, and overall post-harvest quality attributes. This observation contradicts similar findings from the current study as though there was improved K and Mg composition, but the okra shelf life was compromised due to moisture loss accompanied by the presence of fungal pathogens.

5.5 Conclusion

In conclusion, results from the study revealed that soil textural type and Fertilizer combinations had a significant effect in all the measured mineral quality attributes (P, K, Ca, Mg & Fe) whereas variation in soil moisture regime had inconsequential effect on all measure mineral quality attributes. Nevertheless, the interaction between soil type and moisture regimes as well as Fertilizer combinations and moisture regimes exerted a significant effect on P and Mg content of okra. Lastly, moisture regime alone and in interaction with soil textural type and/or Fertilizer combinations significantly influenced the rate of weight loss and appearance of black spots and molds during storage. The findings revealed that integrated use of organic manure and inorganic NPK fertilizer improves the mineral quality of okra even under moisture stressed conditions. Researchers and farmers should collaborate to implement sustainable and effective management strategies based on the specific conditions of their agricultural environment.

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CHAPTER 6

General Summary, Conclusion and Recommendations

6.1 Summary

Okra (*Abelmoschus esculentus*) forms part of the ancient, cultivated crops and is currently cultivated in a number of nations. Its history of distribution commenced from the Ethiopia and Sudan regions to the rest of the world are by no means certain (Kumar et al., 2013). It is an economically important vegetable crop that is widely grown in the tropical and sub-tropical regions (Afe & Oluleye, 2017). Okra is a source of valued nutrients as well as health benefits; and contains high minerals and vitamins content that are key for proper maintenance of human health and prevent diseases such cancer, poor eyesight etc. It is an important source of vitamin C, containing less calories and fat-free (Gemedet et al., 2015). Reports abound on the potential of okra to reduce the chance of kidney problems particularly associated with blood sugar levels through frequent consumption (Santos et al., 2019; Meena & Bhati 2016; Gemedet et al., 2015). Similarly, the consumption of okra has been reported to prevent and help against gastrointestinal problems (Kumar et al., 2013). Okra fruits are generally scarce in the South African retail markets with a very short lifespan and only available for a short period of time during cultivation.

The oil content of the seeds can be as high as that of chicken eggs and soybeans (Olaniyi et al., 2010). Okra is more of a diet rather than a staple food (NRC, 2006). It plays a critical role in a human diet by providing proteins, and vitamin C in bulks (Dilruba et al., 2009). The lipid components from okra have a great potential to contribute to the nutritional value of almost all kinds of food. In addition, carbohydrates are available in the form of mucilage from the leaves of okra (Gemedet et al., 2014). The main composition of sugar units and amino acids available in the fruits of young okra are 24.6% galactose, 21.8% rhamnose, 27.1% galacturonic acid and 11.4 % amino acids (Benchasri, 2012). Okra seeds contain 2.0% protein and 0.19 % oil underscoring the importance in both the food and oil industries (Kumar et al., 2010). Dried okra seeds are highly nutritious and used not only in making vegetable curds but also used as coffee additives or substitutes (Ansari & Ismail, 2001). Okra is rich in vitamin C, a water-soluble nutrient that boosts humans' immune function (Benchasri, 2012).

A generally grown okra under normal conditions with no fertilizer application should give us the approximate nutrient content of 87.7% water, 2.2% protein, 0.3% fats, 7.9% carbohydrates, 1.6% fibre and 0.3% ash (Adewole & Ilesanmi, 2011). However, the nutritional quality of the

crop may be improved by applying organic poultry manure and seaweed (Santos et al., 2019). Fertilizer application improves both the yield and nutritional quality of an Okra crop (Meena & Bhati, 2016). Farmers can choose to use either organic or inorganic fertilizers, or both. The most critical elements available in inorganic fertilizer are Nitrogen, Phosphorous and Potassium. Each element has its own purpose in the growth and development of a plant. These elements are required at different growth stages of the plant (Santos et al., 2019). Variation in soil types also exert significant influence on moisture availability to plants (Islam et al., 2017). The ability of a soil to retain or hold moisture influences the rate at which the plants will grow depending on accessible moisture available from the soil to the plant (Hakeem & Akhtar, 2016). Given the benefits associated with integrated use of natural resources, this study investigated the integrated use of organic and inorganic fertilizers, with variation in moisture regimes and soil textural types as an agronomic package to assist potential okra farmers to overcome the challenges of low yields and quality brought by moisture stress under different soil conditions.

6.2 Research organization

The greenhouse pot trial planted at the UMP experimental farm during January to April 2022, examined the combination effect of moisture regime with varied poultry manure and inorganic NPK fertilizer mix ratios on the growth, yield and quality attributes of okra grown on two soils with distinct textural characteristics. The mineral composition of the harvested okra fruits was chemically analyzed under laboratory conditions. The shelf life of the okra fruits was analyzed at room temperature, packaged in polyethylene bags.

6.3 Main findings from the study

- a. Results of pre-planting soil analysis revealed that the soil textural classes were clay loam and sandy loam soil. The measured pH value was 5.79 (clay loam) and 6.27 (sandy loam) suggesting that the clay loam is mildly acidic whereas sandy loam is slightly acidic. The measured available P level in sandy loam of 31.51 mg kg⁻¹ was adequate while the clay loam value of 8.47 mg kg⁻¹ was just above the critical level of 8 mg kg⁻¹ considered adequate to support plant growth and development (FSSA 2016).
- b. The results of the greenhouse trial revealed the following:
 - Fertilizer combinations exerted a positive influence ($p \leq 0.05$) on growth parameters. Results revealed that the 75:25 PM and inorganic NPK fertilizer managed to enhance growth parameters.

- Fertilizer combination and soil type had a significant effect ($p \leq 0.05$) on the chlorophyll content of okra leaves. The results revealed that the interaction of 25:75 PM and inorganic NPK fertilizer with clay loam soil produced the highest chlorophyll content.
- Moisture stress exerted a negative influence ($p \leq 0.05$) on the number of leaves of okra. The results revealed that the stress caused a decline in the number of leaves per plant.
- Soil textural type had a significant effect ($p \leq 0.05$) on the phenological attributes of okra. Its interaction with Fertilizer combinations or moisture regime also had a significant influence ($p \leq 0.05$) on the initiation of flowers. Fertilizer combinations and moisture regime alone and in interaction, both had a significant effect on the phenological attributes of okra.
- Fertilizer combinations exerted a positive influence ($p \leq 0.05$) on the yield of okra. The integrated use of poultry manure and inorganic NPK fertilizer, with more parts of poultry manure produced yields higher than that of the sole inorganic NPK fertilizer.
- The interaction effect of fertilizer level with soil textural type significantly ($p \leq 0.05$) influenced the dry weight and length of okra fruits.
- The soil textural type exerted a significant influence ($p \leq 0.05$) on the mineral composition of okra fruits. A similar trend was observed with its interaction with Fertilizer combinations. The Fertilizer combinations also exerted a significant effect on the mineral composition of the crop.
- The 21 days of storage significantly affected the magnesium of okra fruits. Its interaction with soil textural types had similar results. However, its interaction with Fertilizer combinations had a significant effect on the potassium and magnesium.
- The moisture regime had a significant effect on the shelf life of okra. Its interaction with the fertilizer level and/or soil textural type also had a significant ($p \leq 0.05$) effect on the shelf life of the crop.
- Based on the findings of this study, the hypothesis that sole and integrated use of poultry manure and inorganic NPK fertilizer and varied soil textural types has no effect on the growth, yield and quality of okra with or without moisture stress was therefore rejected.

6.4 General conclusion

- The study revealed that the introduction of moisture stress affected okra growth, yield and mineral composition under varied soil textural type suggesting that managing moisture stress through appropriate agronomic practice is crucial to promoting increased and sustainable okra production.
- Fertilizer combinations significantly affect the growth of okra. The control treatment produced the lowest growth than all of the Fertilizer combinations. Fertilizer combinations also had a significant effect on the yield and mineral composition of okra.
- The interaction of moisture regime with Fertilizer combinations positively affects the yield and mineral composition of okra. Interaction of no moisture stress with 75:25 PM and inorganic NPK fertilizer produced significantly higher phosphorus and magnesium contents.
- Soil textural types significantly affect the mineral quality of okra fruits. Its interaction with Fertilizer combinations produced similar results. However, its interaction with moisture regime had a significant effect only on the phosphorus and magnesium.
- Extended storage compromises the mineral composition of okra fruits. The interaction of storage with soil textural type significantly affects the magnesium content, whereas its interaction with Fertilizer combinations significantly affects the potassium and magnesium content of okra fruits.

6.5 Recommendations

The results of the study indicate that the integrated use of organic manure and inorganic NPK fertilizer with variable soil textural types and moisture regime can be an effective and inexpensive technique to enhance okra growth, yield and quality attributes. Furthermore, the various soil amendments evaluated were able to improve the mineral composition under limited soil moisture conditions. The results underscore the potential use of organic manure and inorganic fertilizer mix to promote profitable production of high value vegetable crops such as okra. However, we recommend a field validation of these findings under different soil and climatic conditions as part of the process for upscaling the practice. The study illustrates the need for identification of more local AMF strains available on diverse soil textural types and climatic conditions in South Africa to assess the efficiency as a cost-effective and low-input

agricultural product for promoting increase and sustainable okra production under diverse soil and growing conditions.

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