EFFECT OF GOAT MANURE AND PEARL MILLET MULCH ON SOIL MOISTURE AND FERTILITY ON GROWTH AND YIELD OF SELECTED COWPEA VARIETIES IN THARAKA SOUTH SUB-COUNTY

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Award of the Degree of Master of Science in Dryland Agriculture of Chuka University

CHUKA UNIVERSITY
OCTOBER, 2025

DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been previously presented for an award of a diploma or conferment of a degree in any other university or institution

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Recommendation

This thesis has been examined, passed and submitted with our approval as University supervisors.

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DEDICATION

This thesis is dedicated to my lovely wife Domisila Gatonga, son Jayden Gikunda and daughter Peace Gikunda, academic peers and friends who demonstrated moral support and love during my academic journey.

ACKNOWLEDGEMENT

I convey special gratitude to my supervisors Dr. Haggai Ndukhu and Dr. James Kirimi Kiramana in the department of Plant Sciences, Chuka University. Their continuous academic guidance during proposal and thesis writing as supervisors greatly contributed to my success in research work. Their dedication to spend time with me during my research work with suggestions and positive comments made my study a success. Their continuous request to complete my masters was a pillar to my study in times of difficulties. Special appreciation to Prof. Muraya, Prof. Gathungu, Prof. Munyiri, Prof. Grace Opetu, and Dr Njogu lecturers at department of Plant Sciences for theoretical knowledge that acted as ingredients in conducting and completion of my study.

My sincere thanks to my lovely wife Domisila, Son Jayden, and daughter Peace, parents, friends, and course mates, their love and moral support acted as a cornerstone during the study period. Specifically, my family provided moral support that encouraged me to conduct the study. Special thanks to my parents for their unwavering support in performing any undertaking that had the potential for professional and individual growth, especially educational growth. My special thanks to Tharaka University for offering a plot where I conducted field trials for two seasons. Above all, I thank God for His grace to complete my research study.

ABSTRACT

Cowpea acts as source of high quality protein, carbohydrates, calcium, iron and vitamins. In Kenya, cowpea is used for income generation and a key pillar in food and nutrition security among smallholder farmers. However, cowpea production has declined by 19% due to moisture stress caused by unreliable rainfall. This study was conducted to evaluate the effect of goat manure and pearl millet mulch on soil moisture and fertility, growth and yield on selected cowpea varieties in Tharaka South, Sub-County. A survey was conducted in Tharaka South Sub-County on cowpea farming practices. A field experiment was carried out at Tharaka University demonstration farm during rains of October 2023 to January 2024 and March to June 2024 seasons. The experiment employed a Randomized Complete Block Design (RCBD) in a split-plot arrangement, with three replications. Three cowpea varieties served as the main plots, while goat manure and pearl millet stubble mulch were assigned as subplots as treatments. Survey data were analysed using SPSS, while experimental data was analysed using SAS® 9.4. Analysis of variance (ANOVA) was conducted, with means compared at a 5% significance level via LSD (α=0.05). Experimental data collected included soil moisture content, pH, nutrient levels (N, P, K, Ca, C, Na, Cu, Fe, Mn and Zn), plant height, stem girth, number of branches, leaf area, leaf area index, flowers, pods, grains, and grain weight. The findings indicated pearl millet mulch and goat manure had a significant ($p<0.05$) effect on soil moisture, C, N, Ca, Mg, plant height, stem girth, number of branches, number of flowers, pods, grains and grain weight as compared to a control treatment with no inputs. The survey revealed that the major challenges in cowpea production are moisture stress (65%) and soil degradation (30%) and the most preferred cowpea varieties were M66 (44%), KVU 27-1 (36%), and K80 (14%), 65% keeping livestock and crop production, 62% planted seeds from previous harvest, 30% from market and 8% from agro-dealers. Highest soil N (0.69%) and C (1.33%), K (1.94 Cmol kg^{-1}) was recorded in trial I and P (154.4 ppm) recorded in trial II, and control N (0.12%) and C (0.88%), K (1.06 Cmol kg^{-1}) was recorded in trial II and P (12.37 ppm) in trial I. Pearl millet mulch gave the highest moisture percentage of 27.7% at 7 DAS in trial II, plant height of 37.46 cm at 56 DAS in trial two compared to control with moisture percentage of 26.23% at 7 DAS and plant height of 13.33 cm at 56 DAS in trial II. Number of flowers, pods and grains were highest under goat manure at 36.08, 33.08 and 18.33 in trial I, I and II at 49, 56 and 75 DAS, respectively for M66 variety. Yield was highest under goat manure at 4625 kgs per hectare at harvesting compared to control with 1958 kgs per hectare in trial I. The findings recommend the application of goat manure and pearl millet mulch as an effective, sustainable strategy to enhance cowpea yields, improve soil health, and support the livelihoods of farmers in arid and semi-arid regions.

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ABBREVIATIONS AND ACRONYMS

ALVs	**:**	African Leafy Vegetables
GM	**:**	Goat Manure
IITA	**:**	International Institute of Tropical Agriculture
NACOSTI	**:**	National Commission of Science, Technology, and Innovation
PMM	**:**	Pearl Millet Mulch
SWR	**:**	Soil Water Retention

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Cowpea (*Vigna unguiculata*) is the most popular African leafy vegetables (ALVs) consumed in Eastern and Southern Africa as grain and leaf (Hutchinson *et al*., 2016). Cowpea is among the ALVs recommended to alleviate food and nutrition insecurity (Sanfo *et al*., 2023). It is a major source of alternative protein for people living in arid and semi-arid areas (Chiroma *et al*., 2024). In Kenya, cowpea is used for income generation and as a key pillar in food and nutrition security among smallholder farmers (Hutchinson *et al*., 2016).

Globally, cowpea productivity is 5.3 tonnes/hectare with Africa productivity estimated as 1.62 tonnes/hectare, Sub-Saharan Africa 0.52 tonnes/hectare and in Kenya it is 0.84 tonnes/hectare in cowpea production (FAOSTAT, 2020). Kenya is ranked seventh in the world in cowpea production (Owade *et al*., 2020). In Tharaka Nithi County, an average yield cowpea is approximately 0.8 to 1.2 tons/hectare, reflecting modest gains from previous years' 0.5 to 0.8 tons/hectare, as reported by the Kenya National Bureau of Statistics (Kosgei & Agwata, 2021).

Tharaka Sub-County region has experienced a steady upward trend, with yields reaching up to 1.3 tonnes per hectare in some areas due to increased farmer training and access to inputs (Moi, 2021). However, the yield of cowpea is low as compared to its yield potential of 1.5 to 3.0 tonnes/hectare (Osipitan *et al*., 2021). Cowpeas account for 16% of the production of pulses and are produced by 85% of smallholder farmers living in Arid and Semi-Arid Lands (ASALs) of Eastern Kenya and other regions of Western, Central and Nyanza (Njonjo *et al*., 2019).

Cowpea’s ability to withstand drought, short growing period and multi-purpose use makes it a very attractive alternative crop for farmers in marginal, drought-prone areas with low and erratic rainfall (Dutta *et al*., 2021). Cowpea leaves and grains are consumed, used as animal feed and as a cover crop to control soil erosion and enhance soil fertility (Kebede & Bekeko, 2020). The leaves are rich in iron, zinc, vitamins, beta-carotene, protein, carbohydrate, calcium, fibre, and phytonutrients; flavonoids and isoflavones, (Mupangwa *et al*., 2021). The grains contain substantial amount of potassium, magnesium and flavonoids that lower inflammatory disorders and regulate cardiac muscle's normal functioning (Affrifah *et al*., 2022).

Cowpea productivity has however declined recently by about 19% due to low and unreliable rainfall resulting to moisture stress (Kebede & Bekeko, 2020). The decline is attributed to both abiotic and biotic factors with moisture stress reported to be one of the abiotic cowpea production constraints. Among the methods to mitigate moisture stress that has proved inadequate in dry areas is the use of drought tolerant cowpea varieties and irrigation (Motaroki *et al*., 2021). Irrigation, a possible remedy is an unaffordable among small-holder farmers in ASALs (Somasundaram et al., 2020), while the access to drought resistant cowpeas varieties remain unsettled case in these areas due to limited information and cost among the inhabitants (Njonjo *et al*., 2019).

Low yields in cowpea due to moisture stress is broken down into; terminal and intermittent drought with both limiting water supply to support physiological processes (Horn & Shimelis, 2020). Terminal drought is accompanied by decreased moisture resulting in growth retardation, flower abortion and poor pod filling (Sehgal *et al*., 2018). The intermittent droughts occur either in one or two intervals during the growing period (Mosad & El, 2021). Depending on the stage of crop growth, especially during flower formation, intermittent drought results in flower abortion hence low yields (Mosad & El, 2021).

Arid and semi-arid soils are characterized by low fertility and high temperatures (Onyango, 2021). The soils have inadequate moisture due to irregular rainfall, low humus and high pH due to inadequate rainfall to wash soluble salts into lower horizons of the soil (Navuana, 2018). The low water content and infertility lead to reduction or no crop production. Various animal manures have been applied as a nutrition source for cultivated crops (Dutta *et al*., 2021). Irrigation is employed as a management strategy to support rain-fed farming by alleviating moisture stress and improving crop survival (Chen *et al*., 2024). Additionally, farmers use inorganic fertilizers to restore soil nutrients and promote healthy crop growth. However, both irrigation and the use of inorganic fertilizers are often not sustainable for smallholder farmers (Srivastav *et al*., 2024).

Goat manure enhances soil physical fertility by improving aggregate stability and reducing soil bulk density (Muchomba, 2022). Its organic matter content contributes to better soil structure, increasing soil organic carbon (SOC), stabilizing macro-aggregates, and protecting carbon within aggregates (Sajjad *et al*., 2021). This results in a crumb like texture that promotes aeration and root penetration. Improved soil structure also facilitates water infiltration, reduces erosion, and strengthens the soil's capacity to retain moisture (Sajjad *et al*., 2021). In terms of nutrients, nitrogen supports chlorophyll formation for photosynthesis, phosphorus encourages root growth, and potassium regulates essential physiological processes vital for vigorous crop development (Mounirou *et al*., 2023). High nutrient content, efficient heat transfer, and fast decomposition, goat manure releases nutrients quickly, making it highly effective in restoring soil fertility (Washaya & Washaya, 2023). Overall, goat manure serves as a valuable organic fertilizer that improves soil health and supports sustainable agriculture.

Pearl millet is drought tolerant crop surviving in dry and hot areas due to its high water use capacity (Salem & Shoman, 2021). It can be used as residue management to conserve moisture and improve soil nutrients, regulate soil temperature by creating a physical layer to the soil in ASALs (Kumar, 2022). Despite soil fertility improvement and water conservation benefits, stubble mulch and goat manure application is limited by smallholder farmers in ASLS. Stubble mulching is a cheap and readily available water-saving practice that has been shown to conserve soil moisture, regulate temperature, and reduce evaporation (Navuana, 2018). The interception of raindrops and reduction in the intensity of raindrops by mulch curbs the speed of run-off and soil erosion (Sajjad *et al*., 2021). This is critical to boosting the soil water conservation (Somasundaram *et al.,* 2020).

Applying stubble mulch and goat manure can be a cheap, readily available, and sustainable way of increasing water retention and improving soil fertility (Al-Shammary *et al*., 2024). Goat manure and pearl millet stubble as previous crop residue is readily available and cheap for smallholder farmers in Tharaka. However, there is limited information on use of goat manure and pearl millet mulch on cowpea production as a management strategy, for water and soil conservation among smallholder farmers under dryland conditions.

1.2 Statement of the Problem

Cowpea is one of the most important crops in the dry lands due to its drought tolerance characteristics, contributing significantly to the nutrition and health status of people. However, irrespective of its benefits, its productivity is low, primarily due to soil fertility depletion, water scarcity, and suboptimal agricultural practices. The decline in cowpea production has been estimated to be 19% due to irregular rainfall resulting to moisture stress. Traditional and modern farming methods in arid regions often lead to soil degradation, reduced crop yields, and limited sustainable food production. Goat manure and pearl millet mulch are cheap and readily available among smallholder farmers in dryland areas. While organic amendments like manure and mulching practices are known to enhance soil health, improve water retention, and boost crop yields, their effectiveness in improving cowpea production in Tharaka South sub-county remains unexplored. Ultimately, there is limited information on use of goat manure and pearl millet stubble mulch to conserve moisture and improve soil fertility to optimize cowpea production.

1.3 Objectives of the Study

1.3.1 Broad Objective

To evaluate effect of goat manure and pearl millet mulch on soil moisture and fertility, growth and yield on selected cowpea varieties in Tharaka South, sub-county.

1.3.2 Specific Objectives

i. To identify cowpea production practices among farmers of Tharaka South sub-county.
ii. To determine the effects of goat manure and pearl millet stubble mulch on soil moisture levels in Tharaka South sub-county.
iii. To determine the effects of goat manure and pearl millet stubble mulch on soil chemical properties in Tharaka South sub-county.
iv. To determine the effects of goat manure and pearl millet stubble mulch on growth and yield of selected cowpea varieties in Tharaka South sub-county.

1.4 Research Question

i. What are the current cowpea production practices among farmers of Tharaka South sub-county?

1.5 Hypotheses

H_{01}: There is no statistically significant effect of goat manure and pearl millet stubble mulch application on soil moisture levels in Tharaka South sub-county.

H_{02}: There is no statistically significant effect of goat manure and pearl millet stubble mulch application on soil chemical properties in Tharaka South sub-county.

H_{03}: There is no statistically significant effect of goat manure and pearl millet stubble mulch application on growth and yield on selected cowpea varieties in Tharaka South sub-county.

1.6 Justification of the Study

Drought is a major abiotic stress that negatively affects the growth and yield of cowpea crop in arid and semi-arid lands (ASALs). Irrigation is an unsustainable method for smallholder farmers in ASALs (Somasundaram *et al*., 2020). The soils in ASALs have low fertility making them unsustainable for the smallholders farmers to produce cowpeas (Onyango, 2021). Goat manure and pearl millet stubble mulch are cheap and locally available which offer a sustainable way of improving cowpea production. They enhance water and soil conservation under dryland conditions (Al-Shammary *et al*., 2024). Goat manure have ability to boost soil physical fertility by enhancing aggregate stability and decreasing soil bulk density (Islam & Sherman, 2021). They also improve the soil structure, increase soil organic carbon (SOC), macro-aggregate stability, and aggregate protected carbon (Sajjad *et al*., 2021).

The study generates new information useful to smallholder farmers in dryland areas, extension officers, and other stakeholders promoting cowpea production under dryland conditions. The use of goat manure and pearl millet stubble mulch help in improving moisture retention and soil fertility for enhanced cowpea productivity. The use of goat manure and pearl millet stubble mulch which are cheap and readily available among farmers in Tharaka South Sub-County help in reducing the cost of production. It also improves the yield of cowpeas, hence providing high incomes to farmers which further improves their livelihoods while promoting sustainable environmental conservation in ASALs and other dryland areas.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview of Cowpea Production

Cowpea (*Vigna unguiculata*) is a member of the *Fabaceae* family and genus *Vigna* (Mohammed *et al*., 2024). The cultivated species are classified into four races; *textile* used for fibres, catjang used for feeding livestock, asparagus bean used as vegetable (*sesuipedalis*) and *unguiculata*, commonly grown as food and fodder, (Mohammed *et al*., 2024). They are climbing annuals, erect or prostrate depending on variety. They have tap root systems and numerous lateral roots that are spreading to reach out to water (Nkoana, 2018). Cowpea takes 60-120 days to mature, depending on the variety and prevailing climatic conditions (Dhaliwal *et al*., 2022). In Latin America, Asia and Africa *unguiculata* is the majorly grown race (Iqbal *et al*., 2017). Cowpea production account for 16% of the production of pulses and are produced by 85% of small-holder farmers living in ASALs of Eastern Kenya (Njonjo *et al*., 2019).

Globally, cowpea productivity is 5.3 tonnes/hectare with Africa productivity estimated as 1.62 tonnes/hectare, Sub-Saharan Africa 0.52 tonnes/hectare and in Kenya it 0.84 tonnes/hectare in cowpea production (FAOSTAT, 2020). In Kenya is ranked seventh in the world in cowpea production (Owade *et al*., 2020). The yield trends of cowpea (*Vigna unguiculata*) in Tharaka Nithi County, Tharaka sub-region, and Kenya as a whole have exhibited a gradual increase over the past decade, driven by improved agronomic practices, increased adoption of improved seed varieties, and enhanced awareness of nutritional benefits (Kosgei & Agwata, 2021).

In Tharaka Nithi, recent data indicate an average yield of approximately 0.8 to 1.2 tonnes/hectare, reflecting modest gains from previous years' 0.5 to 0.8 tonnes/hectare, as reported by the Kenya National Bureau of Statistics (Kosgei & Agwata, 2021). Similarly, Tharaka sub-region has experienced a steady upward trend, with yields reaching up to 1.3 tonnes/hectare in some areas due to increased farmer training and access to inputs (Moi, 2021). However, the yield of cowpea is low compared to its yield potential ranging 1.3 to 3.0 tonnes/hectare (Osipitan *et al*., 2021). Yield variability remains high, influenced by factors such as drought, pest infestations, and limited access to quality seeds, underscoring the need for continued research and support to sustain productivity growth (Horn & Shimelis, 2020).

Cowpea is a source of high-quality protein (25.4%), carbohydrate (56.8%), calcium, iron, vitamin B, and beta-carotene (Harmankaya *et al*., 2016). It acts as cheap source of dietary protein for low-income groups in developing countries (Ugwu, 2020). Cowpea leaves are eaten directly in Africa (Karavidas *et al*., 2022). Young leaves and immature pods are consumed as vegetables in their fresh form, while the dried grain is utilized to make snacks and main meals (Shehu *et al*., 2022). Cowpea is also an important fodder crop fed to livestock during dry seasons (Owade *et al*., 2020). The haulm, which contains around 20% protein, is a valuable feed that sells for nearly the same price as cowpea grain on a dry weight basis (Shehu *et al*., 2022). Cowpea is considered an adaptable pulse due to its smothering nature, drought tolerance characteristics, soil healing properties, and multiple usages (Arshad *et al*., 2019).

Cowpeas are leguminous crops of different varieties. Farmers in dryland have failed to understand the variety selection criteria (Behera *et al*., 2024). Dryland areas requires a wide range of varieties suitable to such conditions. For example, short-stemmed cowpea cultivars with limited leaf surfaces help at reducing transpiration (Karavidas *et al*., 2022). Similarly, quick-maturing cultivars are needed to develop the crop before the hottest and driest period and mature before moisture supplies are entirely depleted (Biama *et al*., 2020). Deep, prolific root systems improve moisture consumption. Hence, consideration of farmers' understanding to cropping systems, customer preference, and production constraints are critical in adoption of improved varieties and new farming technologies (Kuruma *et al*., 2019). Such consideration helps farmers to cultivate the right varieties at a suitable locality, resulting in an increased yield.

In Kenya, cowpea variety KVU 27-1 is grown to provide vegetables and grains *(Ndiso et al*., 2016). It has dark red grains, purple flowers and pointed leaves, and moderate resistance to leafhopper, aphids and fungal diseases. In one acre its potential yields range at 0.8-1.8 tonnes/hectare (Singh, 2020). Machakos 66 (M66) is a variety grown for grain and leaf production, and it is semi-spreading. The variety takes 80-90 days to reach maturity, flowering at 55-60 days yielding 0.8-1.7 tonnes/hectare (Kuruma *et al*., 2019). M66 is resistance to septoria leaf spot, powdery mildew, scab and yellow mottle virus but moderately resistant to thrips and aphids attack. Katumani 80 (K80) is a cowpea variety that is dual-purpose for both leaves and grain production. The variety is semi-spreading with elongated leaves that have silvery midrib. It can yield 0.8-1.8 tonnes/hectare (Ndiso *et al*., 2016). Kunde mboga is a variety mainly grown to provide vegetables for human consumption. The varieties discussed are sourced from KALRO but the farmers recycle them for planting. About 80% of farmers use seed from informal supply without considering their climatic suitability, vigour, contamination of seed-borne pathogens and physical purity (Njonjo *et al*., 2019).

Drought is a major abiotic factor contributing to reduced crop production that threatens food security in Kenya. Most farmers in ASALs depend on rainfed agriculture which is negatively affected by drought (Owade *et al*., 2020). Terminal drought result to severe drought that results to poor growth and sometimes total crop loss (Oyeyinka *et al*., 2021). The effects of drought on crops are diverse and dependent on adaptive strategy possessed by the plants for stress tolerance, duration of stress, developmental stage and its intensity (Oyeyinka *et al*., 2021).

Water deficit at vegetative stage of a cowpea results to poor plant growth and leaf reduction altering nutrient absorption process due to an environment having low water available to the plant (Johnson *et al*., 2016). Consequently, stomatal resistance leads to reduction in an exchange of gases between the plant and environment. Water stress results to a decreased turgor and water content of the plant with an overall decrease in expansion of cells, thus stunted growth of cowpea (Johnson *et al*., 2016). Hence, a need to create awareness of the importance of stubble mulching that plays a key role in conserving moisture through reduction of evaporation in addition to providing organic matter to the soil (Owade *et al*., 2020).

Cowpea is one of the crop species considered highly resistant against drought at the vegetative phase of growth (Johnson *et al*., 2016). Cowpeas can survive for 43 days after germination and emergence in hot, dry soils without rain but with stunted growth (Horn & Shimelis, 2020). Cowpeas endure drought at the vegetative phase due to high leaf water retention. Cowpeas are characterised by low changes in osmotic potential and leaf water on exposure to drought stress (Johnson *et al*., 2016). Additionally, cowpea leaves possess stomata highly sensitive to drying of the soil that lead to partial closure prior to leaf water potential changes (Ajayi, 2022). Further, cowpeas under drought exposure have their leaves arranged vertically as a way of limiting exposure to solar radiation instead of leaves drying (Oyeyinka *et a*l., 2021).

Cowpea offers an outstanding capacity to withstand drought at vegetative phase where majority crops such as sorghum and millet are killed by drought. According to Horn and Shimelis (2020) testing drought resistance at vegetative stage of cowpea using a screening method of shallow soils in boxes, it was evident 22% of cowpea breeding lines were affected by drought stress out of 190 cowpea samples from the International Institute of Tropical Agriculture (IITA). This affirmed cowpea lines endure drought at vegetative stage due to extraordinary mechanism of the leaves against drought (Oyeyinka *et al*., 2021). Cowpeas were drought resistance at longer period at vegetative stage, compared to crops species experimented such as soybeans, maize, green gram, sorghum, pearl millet, lablab beans, peanuts and groundnuts (Ajayi & Gbadamosi, 2020). However, there is scanty information on the use of pearl millet mulch as a strategy of increasing the duration of moisture retention in the soil.

Cowpea cultivation is highly concentrated in rural areas where majority of farmers have little knowledge about pathogens affecting cowpea (Owade *et al*., 2020). Cowpea crop is prone to diseases that degrade its quality, reduce its yield, and as a result, cause huge losses to farmers (Aliyu & Makinde, 2016). The crops are affected by various pests, many of which act as vectors for diseases (Aliyu & Makinde, 2016). Pests of cowpea include; American ball worm (*Helianthus armiger*), Leaf hoppers (*Empoasca spp*), Fruit worm (*Helicouerpa armiger),* Cutworm *(Spodoptera litura),* Semi-looper *(Chrysodeixiseriosoma),* White fly *(Bemisia tabaci),* Serpentine leaf miners *(Liriomyza trifoli),* Yellow mite *(Polyphagotarsonemus latus),* Thrips *(Ceratothrips reticulatus), Tuta absoluat,* flee beetles, fruit borers and aphids (Owade *et al*., 2020).

Cowpea diseases such as early blight, late blight, bacterial canker and anthracnose affect the quality and quantity of the produce which leads to loss of income (Aliyu & Makinde, 2016). These diseases cause quality and quantity losses, as well as monetary losses, and farmers are sometimes forced to use varieties that are less resistant to diseases (Palma-Velásquez & Zambrano-Gavilanes, 2023). In many cases, these varieties are less productive, costlier and/or commercially less profitable than other varieties (Aliyu & Makinde, 2016). Bacterial, viral and soil-borne fungal diseases are common diseases resulting in yield reduction in cowpeas (Owade *et al*., 2020).

2.2 Effects of Goat Manure and Pearl Millet Stubble Mulch on Soil Moisture Retention

Soil water retention (SWR) is a measure of the amount of water that a particular soil can hold (Singh, 2020). This is a critical soil property related to pore space (Eden *et al*., 2017). Soil texture, soil structure and soil organic matter (SOM) influences the pore spaces of soil (Mohammed *et al*., 2024). Soil water retention plays a critical role in plant growth influencing crop yield and acting as the main source of moisture to soil biota (Civeira, 2019). Each grain is surrounded by a continuous film of water in the soil (Pronko *et al*., 2022). Water is pushed up from below to replenish evaporated water near the surface, weakening the layer. Wilting occurs when the soil gets too thin for plant roots to absorb (Demir & Gülser, 2021).

2.2.1 Effects of Goat Manure Application on Soil Moisture Retention

Goat manure refers to the biological waste excreted by goats, which is rich in essential nutrients such as nitrogen, phosphorus, and potassium (Rashmi *et al*., 2022). Its application as an organic fertilizer plays a vital role in enhancing soil fertility and promoting healthy crop growth (Singh, 2020)**.** Applying goat manure to soil also significantly influences soil moisture retention, primarily through its effects on soil structure and organic matter content. Organic amendments like goat manure improve soil porosity and water-holding capacity by enhancing aggregate stability and increasing the organic matter fraction, which facilitates better infiltration and moisture retention (Rashmi *et al*., 2022).

Manure introduces decomposable organic materials that increase the soil's capacity to retain water, especially in sandy and loamy soils where moisture retention is typically limited (Rasel *et al*., 2020). Furthermore, goat manure's nutrient content promotes healthy soil microbial activity, which further enhances soil aggregation and porosity, indirectly contributing to improved moisture retention (Johan *et al*., 2021). Several studies have demonstrated that soils amended with goat manure exhibit higher field capacity and reduced water runoff, indicating improved moisture conservation (Rasel *et al*., 2020).

Application of goat manure not only supplies essential nutrients but also plays a vital role in enhancing the soil's physical properties related to moisture retention, which is crucial for sustainable crop production in semi-arid and degraded soils. When goat manure is incorporated into the soil, it improves nutrient availability, stimulates microbial activity, and enhances soil structure (Tayyab *et al.*, 2018). In Northern Nigeria, Smith *et al*. (2019) found that the application of goat manure significantly increased both the biomass and grain yield of cowpeas compared to untreated controls.

Goat manure contains organic matter that improves the soil structure. The importance of soil structure in agricultural and natural ecosystems for managing or modulating the distribution, movement, and retention of water, solutes, gases, and biota is undeniable (Sharma *et al*., 2015). Soil fertility management necessitates the preservation of ideal soil physical conditions allowing water infiltration and retention (Kumar *et al.*, 2022). Crop root growth and efficient exploration of the soil profile for water and nutrients are typically restricted by the breakdown of soil aggregates and the resulting poor soil structural state, especially in salt-affected areas (Olk *et al*., 2018).

Salt-affected, soil amelioration by goat manure application is considered applicable in decreasing soil bulk density (Olk *et al*., 2018). The manure has long been used to improve the fertility of agricultural fields as a source of plant nutrients and organic matter improving soil chemical, biological and physical properties (Kumar *et al*., 2022). Continued decomposition of goat manure in the soil leads to bacteria and microbes absorbing its nutrients releasing their products regarded as humus, often attaching to the soil particles (Mkomwa *et al*., 2023). The humus helps in the separation of dense particles in clay soil enhancing its drainage thus filling the large particles leading to holding more water (Elnasikh & Satti, 2017).

The physical, chemical and biological qualities improve when organic manures are mixed into soils (Elnasikh & Satti, 2017). Several studies have shown that goat manure improves soil structural integrity by lowering bulk density, increasing porosity, boosting water penetration rate, and enhancing saturated hydraulic conductivity (Mkomwa *et al*., 2023). Furthermore, the function is required for coastal tidal flat soil amelioration, which includes increasing soil physical qualities (bulk density, total porosity, and pores distribution), limiting salt deterioration, and promoting effective leaching (Elnasikh & Satti, 2017).

Studies by Raju & Menon, (2020) reported that integrating goat manure into the soil improved nutrient availability and enhanced the growth parameters of leguminous crops such as cowpeas and chickpeas. Their findings indicated that crops treated with goat manure showed higher chlorophyll content, better plant vigor, and increased pod production. Additionally, in Northern Ghana, Senesi (2024) observed that using goat manure as a soil amendment elevated soil nitrogen levels and resulted in a 25% increase in cowpea yield relative to chemical fertilizers alone. These studies collectively demonstrate that goat manure is an effective organic fertilizer that can substantially improve crop productivity by enriching soil nutrients and fostering healthy plant development.

Studies by Raju and Menon (2020) reported limited or inconsistent benefits of integrating goat manure into the soil for leguminous crops like cowpeas and chickpeas. In India, Khan *et al*. (2021) observed that the application of goat manure did not significantly improve nutrient availability or crop yields in certain soil types, particularly those with high organic matter content or poor drainage. They noted that in some cases, excessive application of goat manure could lead to nutrient imbalances or phytotoxicity, adversely affecting plant growth. Additionally, Khan *et al*. (2021) found that unless properly composted or processed, raw goat manure might introduce pathogens or weed seeds, which could hinder crop development in India. These conflicting findings suggest that the effectiveness of goat manure as a fertilizer may depend on factors such as manure quality, soil conditions, and application methods, highlighting the need for careful management to realize its potential benefits. However, there is limited information on the effect of goat manure on soil moisture retention in ASALs.

2.2.2 Effects of Pearl Millet Stubble Mulch Application on Soil Moisture Retention

Pearl millet stubble mulch refers to the residual plant materials left in the field after the harvest of pearl millet (*Cenchrus americanus*), a drought-tolerant cereal crop widely cultivated in arid and semi-arid regions (Taak *et al*., 2021). This residual biomass comprises stems, leaves, and other plant parts that remain on the soil surface or are incorporated into the soil profile. Pearl millet mulch plays a vital role in soil health and fertility by contributing organic matter, reducing soil erosion, and influencing moisture conservation (Gabhane *et al*., 2019). Its presence can also impact nutrient cycling, microbial activity, and subsequent crop performance, making it an important component in sustainable land management practices, especially in dryland cropping systems (Gupta *et al*., 2022).

Tree or shrub shelter belts reduce wind speeds and cast shadows, reducing evaporation by up to 30% and reducing wind erosion (Shukla & Behera, 2020). According to Lian *et al*. (2016) use of pearl millet stalks reduces wind velocity at the surface and lowers soil temperatures in Pengyang city, Ningxia, China. To restore the discontinuity, tillage should be performed after each rain (Bayrakli *et al*., 2023). This is most practical when rainfall occurs in a few heavy rainstorms separated by somewhat long intervals (Hossain *et al*., 2021). However, information on testing moisture retained in soil before sowing and after harvesting while applying pearl millet stubble mulch is scanty.

Mulches help agricultural plants save water by reducing their irrigation needs, and in rare cases, they can eliminate the need for irrigation (Taak *et al*., 2021). Studies have shown organic mulches behave as sponges, retain rainfall and irrigation water and preventing runoff while providing water when crops are in need (Hossain *et al*., 2021). Because the pearl millet straws were used as mulch, the runoff was reduced by 43% (Sukanya *et al*., 2024). Mulches reduce the need for supplemental irrigation by retaining water and lowering soil profile drainage simultaneously (Taak *et al*., 2021). Mulching protects the soil surface and helps keep the soil temperature stable, which is advantageous to crop growth.

Mulch keep the soil cool during extremely hot weather while keeping it at a normal/warm temperature during colder days (Adebayo *et al*., 2025). Temperature extremes have a negative impact on newly emerging plant roots, limiting nutrition and water intake (Sayarer *et al*., 2023). Severe temperatures may stress plants during their early growth stages because their newly developed roots are unable to absorb the correct amount of water and essential plant nutrients (Taak *et al*., 2021). Soil temperature maintenance and modulation are vital aspects for optimal plant growth.

According to the study conducted, use of crop residues reduced the temperature by 10°C (barren soil) in hot and dry desert situations (Mohammed *et al*., 2024).

Numerous studies highlight the benefits of pearl millet stubble mulch in conserving soil moisture and enhancing cowpea yields in arid and semi-arid regions, however, some researches present contrasting findings or highlight limitations that warrant consideration. Sukanya *et al*. (2024) in India, reported that organic mulches, including millet stubble, sometimes led to increased pest and disease incidence, which may negatively impacted cowpea yields. They observed that millet residues could harbor pests such as pod borers or fungal pathogens, necessitating additional management practices. These biotic challenges could offset the benefits of moisture conservation, especially in environments where integrated pest management is not practiced. Lian *et al*. (2016) in Pengyang city, Ningxia, China, conducted a meta-analysis of mulching practices in arid zones and found that the efficacy of millet stubble mulch varied widely depending on local climate, soil type, and crop management in China. Their results indicated that in some cases, mulch application led to increased soil moisture but did not translate into significant yield gains, possibly due to nutrient immobilization or poor mulch placement. There is limited information on the improvement of soil moisture through application of pearl millet mulch in ASALs.

2.3 Effects of Farmyard Manure and Pearl Millet Stubble Mulch on Soil Chemical Properties

Soil chemical properties refer to the characteristics of soil that relate to its chemical composition and reactivity, which influence soil fertility, nutrient availability, and overall soil health. These properties determine how well soils can support plant growth and are essential for assessing soil quality and suitability for agriculture. The chemical properties of soil are essential in water and soil utilization of a crop through water-nutrients balance in the soil (Adebayo *et al*., 2025). Buffering action, soil reaction, colloidal properties, and organic and inorganic matter are significant aspects of soil chemical properties (Karuku *et al*., 2018). Humus percentage and content of organic matter determine the chemical properties of soil (Semida *et al*., 2015). Therefore, correct and balanced physical and chemical properties of soil result in soil functions and optimal biological properties.

2.3.1 Effect of Goat Manure on Soil Chemical Properties

Goat manure supplies phosphorus, nitrogen, potassium, calcium, magnesium and other nutrients altogether warm the soil due to microbial activities breaking down organic compounds releasing energy, thus speeding up decomposition (Murhekar *et al*., 2021). Goat manure significantly regulates the pH and acidity levels of the soil due to its long residual effect compared to using inorganic fertilizers that are nitrogenous or basic quickly releasing nutrients increasing or decreasing soil pH (Yoshimura *et al*., 2023). Hence, the decomposition of organic manure influences the nitrogen supply, carbon to nitrogen ratio, cation exchange capacity (CEC), and pH of the soil. Microorganisms' activities are optimal at a pH of 6-7 when most nutrients are available in the soil (Lee *et al*., 2021).

Goat manure significantly affects the electrical conductivity of the soil as well as controls it's pH (Murhekar *et al*., 2021). Electrical conductivity is a crucial factor serving as a key determinant of the health of soil (Meghvansi & Varma, 2015). It affects crops suitability, yields, the activity of soil micro-organisms and the availability of plant nutrients (Murhekar *et al*., 2021). This presents a significant influence when it comes to the emission of greenhouse gases such as methane, nitrogen oxide and carbon dioxide. Goat manure has a buffering ability and this regulates the soil pH (Kinyumu, 2023). In acidic soils, GM significantly raises the pH levels. Nevertheless, in alkaline soils, it reduces the pH (Meghvansi & Varma, 2015). This results in the creation of a relatively favourable condition when it comes to the nutrient availability and uptake by plants, that is a pH range of 6.5 to 7.8 (Kassam & Mkomwa, 2022). Goat manure determines the physical and physio-chemical soil properties (Warr, 2019).

The group of soil microorganisms that dependent on mineralizing bacteria optimize at pH 6.5-8 while fungi at 5.5-6.5 (Tolossa, 2023). Increased electrical conductivity (EC) and soil pH rarely interfere with soil microorganisms' nitrogen mineralization (Meghvansi & Varma, 2015). Nitrification of soils rapidly occurs at pH between 5.0 to 6.0 (Wamalwa, 2024). Goat manure contributes significantly to the improvement of soil chemical properties (Sajjad *et al*., 2021). However, there is scarce information available on the changes in soil chemical properties due to application of goat manure.

Organic manure influences physical, chemical, and biological qualities of soil fertility. The production of clay humic complexes in the soil enhances the adsorption capacity of basic nutrients (calcium, magnesium, and potassium) and increases the activity of microorganisms in the mineralization process (Wamalwa, 2024). Adding organic residues to the soil can also help to raise the pH significantly (Wamalwa, 2024). This is due to higher levels of basic nutrients in organic amendments and lower levels of soil hydrous oxides (Meghvansi & Varma, 2015).

Inorganic nutrients are the only ones that plants can utilize. Because manures contain both organic and inorganic forms of nitrogen and phosphorus, their organic forms are completely unavailable to plants (Wamalwa, 2024). Before plants absorb organic forms, they must be mineralized or transformed into inorganic forms over time (Meghvansi & Varma, 2015). The bulk of potassium (K) in manure is in the inorganic form, its availability is comparable to that of commercial fertilizer (Podrázský *et al*., 2016). During the first year of treatment, 90 to 100 percent of the potassium in manure is available (Chiroma *et al*., 2024). Phosphorus levels in the soil are also increased by FYM. Most crops have significant manure requirements, ranging from 5 to 20 tons of fresh manure per hectare (Sajjad *et al.,* 2021). When manure is applied, it progressively mineralizes, and nutrients become available in the soil and to plants.

Studies caution that the effects of goat manure are not universally beneficial and may sometimes lead to adverse outcomes. For instance, Owade *et al*. (2020) found that while organic manure like goat manure can lower soil pH, excessive or poorly managed applications may lead to undesirable soil acidification, potentially harming plant growth and microbial communities. Moreover, the rapid decomposition of manure can cause spikes in soil electrical conductivity, leading to salinity issues if not properly managed. Additionally, Fierer *et al*. (2021) in Santa Barbara, USA, noted that in certain soil types particularly those already high in soluble salts adding goat manure might exacerbate salinity problems, negatively affecting plant water uptake and growth. They emphasized that the impact of manure on soil chemical properties is highly context-dependent, requiring careful application and monitoring. There is limited information on the application of goat manure on soil chemical properties in ASALs.

2.3.2 Effect of Pearl Millet Stubble Mulch on Soil Chemical Properties

Stubble mulch serves a significant function in improving the soil's physical, chemical, and biological qualities (Wamalwa, 2024). The organic matter released from decomposing stubble increases the nutrient content in the soil especially nitrogen, phosphorus and potassium. This supports subsequent plant growth (Shukla & Behera, 2020). It protects soil from wind and water erosion, reduces run-off, and serves as a physical buffer (Shukla & Shanker, 2019). Adding straw to the soil improves organic matter, promotes aggregate development and structural stability. It decreases the bulk density of the soil and enhances its porosity. Organic matter in the soil is stored for critical plant nutrients, preventing leaching and increasing cation exchange capacity (Shukla & Shanker, 2019). Using agricultural wastes regularly increases the soil's organic matter while boosting its water retention ability. Crop wastes aid carbon sequestration in soils (Chiroma *et al*., 2024). The organic mulches help to neutralize acidic soils over time by gradually raising the pH to a more optimal level for plants growth (Chiroma *et al*., 2024).

Agricultural procedures determine the use of mulches in the field, whether partially or totally (Das *et al*., 2023). It is beneficial for recycling residue, and the higher C: N ratio must be compensated by providing more nitrogen fertilizer during residue integration (Wamalwa, 2024). Rice output was reduced in the first three years of straw addition 30 days before rice planting because crop residue used in the field may have caused soil nitrogen immobilization (Wamalwa, 2024). However, it had little effect on the yield later on. Studies have explored the use of pearl millet as a mulch to enhance soil chemical properties across various cropping systems.

Studies by Meena *et al*. (2017) in Agronomy farm of Rajiv, Gandhi South Campus of India, demonstrated that mulching with pearl millet biomass in cowpea cultivation increased soil organic carbon, nitrogen content, and cation exchange capacity (CEC), leading to improved nutrient availability and soil fertility. Similarly, Kumar *et al*. (2024) in India, reported that pearl millet mulch applied to maize and bean crops resulted in elevated levels of soil nutrients such as phosphorus and potassium, along with enhanced microbial activity and crop yields. Verma *et al*. (2024) found that in saline-affected soils, pearl millet mulch helped buffer soil pH and reduce salinity impacts by conserving moisture and diluting soluble salts, thereby improving soil chemical conditions.

Studies conducted by Sharma *et al*. (2015) in India, highlighted the role of pearl millet mulch in reducing soil erosion and nutrient leaching, which contributed to the maintenance of soil chemical integrity over time. Overall, these studies conclude that pearl millet mulch significantly improves soil chemical properties by increasing organic matter, stabilizing pH, and enhancing nutrient retention, ultimately promoting better crop performance. Based on these findings, it is recommended that pearl millet mulch be integrated into cropping systems with appropriate application rates and timing to maximize soil health benefits, emphasizing the importance of site-specific management practices to optimize its positive effects. However, there is limited information on use of pearl millet mulch on soil chemical properties in ASALs.

2.4 Effect of Goat Manure and Pearl Miller Stubble Mulch on Cowpea Growth and Yield

2.4.1 Effect of Goat Manure on Cowpea Growth and Yield

Different organic manure treatments considerably impact cowpea growth characteristics such as plant height, leaf area index, length of the pod, and number of grains per pod and grain yield (Gumbeze *et al*., 2024). Plant development results from the photosynthetic activity and photosynthate translocation within the plant, both of which depend on the plant's ability to utilize available nutrients (Parab & Yadav, 2024). Higher plant height came from an initial nitrogen boost that aided in higher chlorophyll production and, as a result, higher photosynthesis (Anyoni *et al*., 2024). Nitrogen is also linked to cell elongation. According to study from Rwanda, Gumbeze *et al*. (2024) noted, the goat manure was incorporated into the soil by grounding the manure with the tilled soil and cowpea seed sown two weeks post incorporation at a planting distance of 50 cm x 50 cm (Ngosong *et al*., 2020). Goat manure influenced the nodulation of the cowpea varieties. The yield of cowpea improved with the application of goat manure with significant difference in the number of nodules among the cowpea varieties (Ngosong *et al*., 2020).

Phosphorus is also known to promote cell division, which helps plants grow taller (Parab & Yadav, 2024). With the application of NPK, the crop's overall vegetative growth improved (Elyasi Rad *et al*., 2025). The effects of goat manure treatments on cowpea yield and yield characteristics are also substantial. More pods, the highest green pod output, and the highest stover production may be related to flower survival under an increased supply of photosynthates with goat manure treatment compared to other organic sources (Gumbeze *et al*., 2024). Research by Ngosong *et al*. (2020) demonstrated that incorporating goat manure into the soil increased essential nutrients such as nitrogen, phosphorus, and potassium, which resulted in improved growth and yields of crops like bean and maize.

Similar studies by Wamalwa (2024) reported that goat manure application elevated soil pH, organic carbon, and cation exchange capacity, thereby enhancing soil fertility and microbial activity. These studies consistently found that goat manure serves as an effective organic supplement, promoting nutrient mineralization and improving soil chemical conditions conducive for crop development. The conclusions drawn suggest that goat manure not only supplies vital nutrients but also improves soil health and structure over time. Consequently, the researchers recommend the regular use of goat manure as part of integrated soil fertility management practices, emphasizing the importance of proper application rates and timing to maximize benefits while minimizing potential nutrient runoff or environmental impacts. Information on application of goat manure on growth and yield of cowpea is limited in dryland areas.

2.4.2 Effect of Pearl Millet Stubble Mulch on Cowpea Growth and Yield

Pearl millet stubble mulch is both a waste material and renewable resource, rich in nitrogen (N), phosphorus (P), and potassium (K) all essential for crop growth and yield. According to (Jabran, 2019), farmers have resorted to using grass and leaf litter in addition to available crop residues. Pearl millet stalks improve water retention capacity of the soil. Low soil productivity triggered research on different strategies for restoring and improving soil fertility. Farmers have resorted to applying plant materials as mulch with remaining crop residue (Gumbeze *et al*., 2024). However, use of plant residues can introduce nitrogen immobilization leading to lower yield.

C: N refers carbon to nitrogen mass ratio in soil organic matter. Application of goat manure in the soil lowers C: N since it adds nitrogen and organic carbon, whereby nitrogen is high and readily available for microorganism promoting faster decomposition releasing nutrients to soil microorganisms converting nutrients to forms available to crops (Traoré *et al*., 2021). Pearl millet stubble mulch temporary immobilizes nitrogen due to high C: N as microorganisms uses nitrogen to break down carbon, with time dissolved organ carbon content and soil organic carbon is increased and nutrient released (Hosseini Bai *et al*., 2014). In long term soil organic matter soil microbial biomass and nutrients are improved. Pearl millet stubble mulch upon decomposition as manure has multiple benefits due to the balanced supply of nutrients, including micronutrients, increased soil nutrient availability occasioned by increased soil microbial activity, soil structure improvements, root development, increased soil water availability (Hosseini Bai *et al*., 2014).

Abiotic variables contribute to the soil's loss of moisture and subsequent conversion to barren land high winds, high temperatures, harsh climatic conditions, and competing plantations, such as weeds (Jabran, 2019). The presence of weeds has been estimated to result in a loss of up to 25% of water due to evapotranspiration (Sarkar *et al*., 2020). Mulches can potentially reduce weed infestation and evaporation losses while improving soil percolation and retention. It has been reported that straw mulch can reduce evaporation by up to 35% (Sayarer *et al*., 2023).

Organic mulches can better conserve soil water than synthetic mulches (Jabran, 2019). To preserve soil moisture, livestock wastes, crop residues, and various stone gravels are commonly used as mulch materials (Kassam & Mkomwa, 2022). Accordingly, mulches outperform cover crops because cover crops are considered competitors to the main crop of interest, competing for water resources. Organic mulches are more helpful since they may degrade in the right setting and provide nutrients (Lichtfouse, 2016). Stubble mulches supply more nutrients than inorganic mulches (Jabran, 2019). However, the information on benefits of pearl millet straws as stubble mulch is limited.

Mulching with pearl millet biomass enhances soil organic matter, nitrogen, and phosphorus levels, leading to increased soil fertility and better growth conditions for crops like cowpea, maize, and beans (Kumar *et al*., 2024 and Singh, 2020). These investigations also found that pearl millet mulch contributes to improved soil moisture retention, reduced erosion, and stabilization of soil pH, particularly in acidic or saline soils. The general conclusion from these studies indicates that pearl millet mulch can serve as an effective organic amendment to enhance soil chemical properties, which in turn promote higher crop yields. Based on these findings, it is recommended that farmers incorporate pearl millet mulch into their cropping systems at appropriate application rates and timings. The information related to incorporation of pearl millet mulch on growth and yield of cowpeas is limited in ASALs.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site Description

The study was conducted in Tharaka South, Tharaka-Nithi County (Figure 1), during October 2023 to January 2024 and March to June 2024 for trials 1 and 2, respectively. The experiment was carried out at Tharaka University demonstration farm located at latitude coordinates of 0° 10’27.9’’South, and longitude 37°53’ 55.4’’ East, and an altitude of 600 meters above the local sea level. Tharaka University experiences temperature ranges of 21 to 36°C and rainfall ranges of 100 to 640 mm per annum (Mugure *et al*., 2023). Soils are Ferric Luvisols, with pH of 6.0 and low fertility. About 65.20% of the human population in Tharaka are farmers keeping livestock and crop production (Figure 3). Cowpea is grown in this area despite the erratic rainfall and soil infertility.

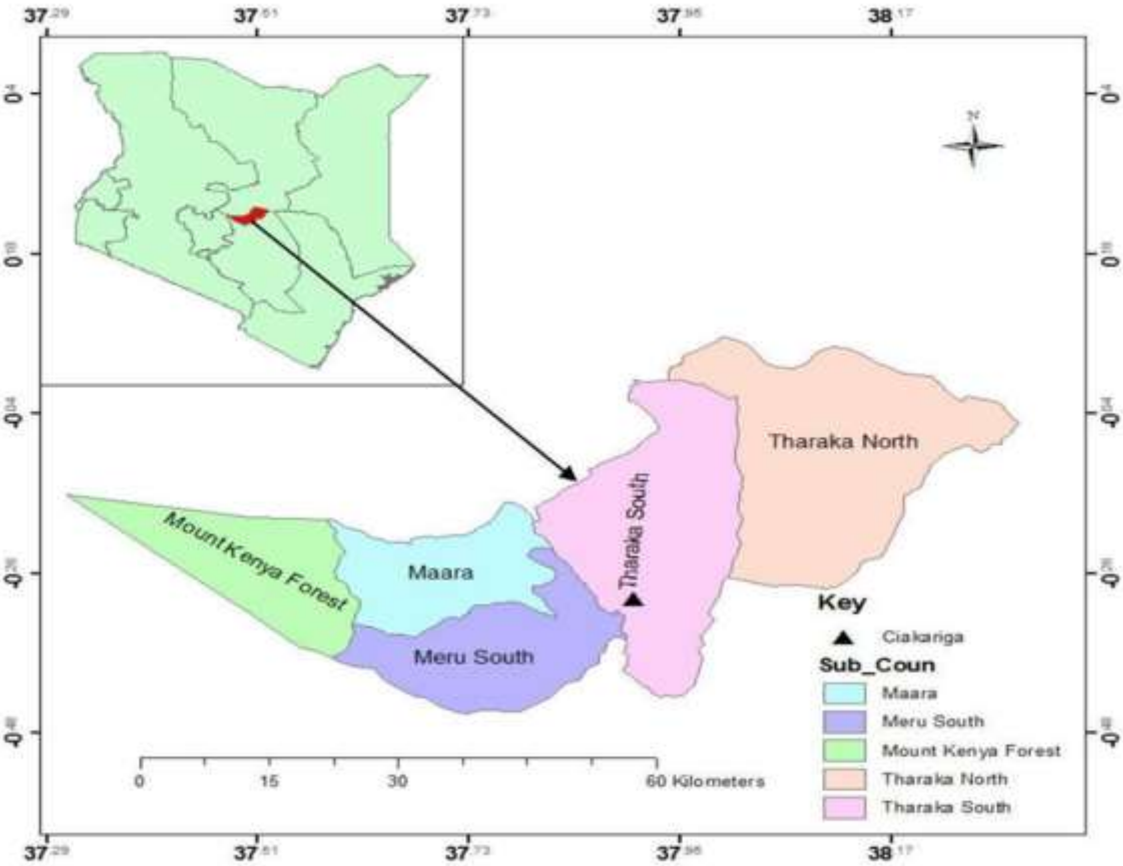

Figure 1: Map of Kenya showing Tharaka South sub-county in Tharaka-Nithi County

Source: (TNC, 2021)

3.2 Survey Research Design

A cross-sectional research design was used to survey farmers on preferred cowpea varieties, production, constraints, utilization, and farmyard manure and stubble mulch application. The survey was conducted at Nkondi, Marimanti, and Chiakariga wards in Tharaka South sub-county. Random selection was used to identify the 64 participants from households growing cowpeas. The survey used a closed-ended questionnaire (Appendix 4), where respondents chose a response among the options. The survey data collected were on cowpea varieties, production, and utilization, constraints, and farmyard and stubble mulch application.

3.2.1 Target Population

The respondents for the population of study were obtained from Nkondi, Marimanti, and Chiakariga wards, Tharaka South Sub-County (Table 1).

Table 1: Sample Size

Ward	Households	Sample size
Nkondi	11,157	16
Marimanti	10,364	14
Chiakariga	24,590	34
Total	46,111	64

Source: (KNBS, 2019)

3.2.2 Sampling Procedure and Sample Size

According to Benedetti and Piersimoni (2017) a coefficient of variation of 20% acceptable in surveys was used to obtain the sample size using Izabayo & Njenga (2022) formula. Tharaka South has a total of 46,111 households (KNBS, 2019).

$n = \frac{NC^2}{C^2+(N-1)e^2}$……………………………………………………………..equation i

Where,

N = population from which sample size is determined

n = desired sample size

e = Standard error, given as 0.025

C = Coefficient of variance, 0.2 (20%)

$$63.91 = \frac{46111(0.2)^2}{0.2^2 + (46111 - 1)0.025^2}$$

Thus, 64 participants were selected randomly among households growing cowpeas.

3.2.3 Research Instruments

Closed ended questionnaire was used to collect information on cowpea varieties, production, utilization, constraints, and farmyard manure and stubble mulch application in Tharaka South sub-county, Tharaka-Nithi County, Kenya (Appendix 4).

3.2.3.1 Pilot Study

Seven farmers growing cowpeas were randomly selected at 10% as recommended for a survey, as a pilot sample out of 64. Piloting was carried out at Mitunguu, South Imenti sub-county, Meru County, a place with similar conditions as Tharaka South. The contents and clarity of questions of the questionnaires were checked, and necessary corrections were effected. Pilot study was useful in evaluating the feasibility of baseline survey through identification of missing information and misunderstanding on the instruments of research (Doody & Doody, 2015).

3.2.3.2 Validity

Content validity of the questionnaire to collect accurate data was conducted by supervisors to ensure that questionnaire gathered intended information accurately. The questionnaire was verified by the supervisors and administered to respondents during pilot study, assessing the questionnaire consistency.

3.2.3.3 Testing Research Instrument Reliability

Using data of seven respondents obtained from the pilot study conducted at Mitunguu (Table 2), the instruments reliability was determined using Cronbach alpha test, a reliability coefficient range of 0.7 to 0.9 is considered acceptable (Taherdoost, 2016). The coefficient was found to be 0.873, making the instruments reliable.

Table 2**:** Coefficient of tested research instrument

Reliability Statistics	
Cronbach's Alpha	N of Items
0.873	7

The following Cronbach alpha test formula was used.

$$\alpha = \frac{K}{K-1}\left[1 - \frac{\sum S^2{}_Y}{S^2{}_X}\right] \text{..........equation ii}$$

Where α = Cronbach alpha, K is sum of test items, $\sum S^2{}_Y$, sum of item variance and $S^2{}_X$ the variance of total score.

3.3 Field Experiment Design, Treatments and Layout

An experimental field trial was laid in a randomized complete block design (RCBD), in a split-plot arrangement with three replications. The experimental plot measured 19.9 m by 6.4 m (127.36 m^2). The experimental units measured 2.1 m by 1.8 m (3.78 m^2). The guard rows measured 0.5 m between main plots and replicates, the spacing between rows and plants was 60 cm and 30 cm respectively translating to 32 cowpea plants per experimental unit. The plant population was 864 in the experimental plot, translating to 84,657 plants per hectare. The experimental units had four lines, whereby each line was composed of eight cowpea plants. The main plots had M66-variety 1, K80-variety 2, and KVU 27-variety 3, whereas pearl millet mulch (PMM), goat manure (GM) and control (free of goat manure (GM) or pearl millet mulch (PMM), were the sub-plots as treatments. Well decomposed goat manure easily friable and without odor, was used at rate of 3.78 kg per experimental unit totaling to 34.02 kg of GM for 9 experimental units equivalent to 10 tha^{-1}. 3.31 kg chopped pearl millet straws were used per experimental unit totaling to 29.77 kgs of PMM for 9 experimental units equivalent to 8.75 tha^{-1}.

3.3.1 Land Preparation and Crop Establishment

Seeds of cowpeas were sourced from an agro-dealer in Tharaka South after gathering the insight on preferred cowpeas varieties. The land was cultivated so as to expose pests, predators and sunlight, pulverize the soil and prepare a good tilth for high cowpea germination percentage and growth using a hoe. Goat manure was sourced from a single farmer in Tharaka South to avoid variability. Goat manure was applied by hand and incorporated along furrows to a 10 cm depth. The goat manure incorporation ensured it was well pulverized with the tilled soil. The goat manure was applied two weeks prior to planting at rate of 3.78 kg/experimental unit, translating to 10 t/ha as recommended rate (Agbo-Adediran *et al*., 2020). Pearl millet stubble mulch was used at the rate of 3.31 kgs/experimental unit, translating to 3500 kg/acre (8.75 tha) as recommended rate (Sosibo *et al*., 2022). The pearl millet stubble mulch was applied after land cultivation. Upon land preparation cowpea seeds were sown at the rate of 3 seeds/hill (9 kg/acre) using the dibbling method. Cowpea seeds were planted to a depth of 4 cm with a spacing of 60 cm by 30 cm. After two weeks seedling were thinned to one seedling per hill.

Hand weeding of experimental units was carried out in two stages. First weeding, carried out at first 2 weeks of emergence and second one before the flowering stage. Timely weeding promoted maximum utilization of growth resources for optimal growth and productivity (Singh *et al*., 2018). Regular and timely scouting of pests were done by spraying with Acetamiprid 150 g/L and Cypermethrin 50 g/L, and Emmamectin benzoate 19 g/L as active ingredients to control sucking and cutting pests respectively at 10 ml in 15 litre knapsack sprayer.

Plate 1: Field layout after emergence and cowpea varieties

3.3.2 Harvesting and Storage

Harvesting was carried out when the pods were drooping and turned colour depending on the variety planted (Das & Fakir, 2014). The pods were gently removed from the plants using hands without damaging the seeds. Proper drying was done after threshing to avoid post-harvest losses.

3.4 Data Collection

3.4.1 Effects of Goat Manure and Pearl Millet Mulch on Soil Moisture Levels

The data on moisture levels were taken before sowing of cowpeas. Also, moisture levels were measured and recorded on weekly intervals up to podding stage. Gravimetric method was used to determine moisture levels using oven drying method. On mass basis, 100 g of wet soil from 17 experimental units was weighed and put in an oven for 24 hours at 105°C to obtain weight oven-dried soil samples (Ahn *et al*., 2014). Tharaka University offered a laboratory for analysis of percentage of soil water. The gravimetric soil water content was obtained by the formula below (Reynolds, 2013):

$$\mathrm{W}\ (\%\ \text{of soil water}) = \left[\frac{\text{weight of wet soil (g)} - \text{weight of dry soil (g)}}{\text{weight of dry soil (g)}}\right] \times 100$$

3.4.2 Effects of Goat Manure and Pearl Millet Mulch on Soil Chemical Properties

Goat manure was obtained from one farmer within Tharaka South to avoid variation arising from different sources. The goat manure sample (300 g) was analyzed for; pH, P, C, N, K, Mg, Ca, Cu, Fe, Mn, and Zn. The process of soil sampling was zigzag, taking soil a to depth of 0-25 cm using an auger (Wang *et al*., 2019). A composite soil sample of 300 g picked from four points per plot was taken and packed separately in sterilised bags for soil analysis. One soil sample was taken per experimental unit for 27 experimental units in trial I and II. The soil samples, were locked in zip bags and taken to the University of Nairobi, soil laboratory, Upper Kabete Campus in the same day to minimize variation. The soil samples were subjected to sieving by a 2 mm diameter sieve for chemical analysis of; soil reaction (pH), available phosphorus, organic carbon (C), total nitrogen (N), exchangeable cations (Ca, K and Na), Cu, Fe, Mn and Zn.

Soil reaction (pH): The pH was measured with a glass electrode pH meter on 1: 2.5 ($^{w}/_{v}$) suspension of soil in water, and on 0.01M $CaCl_2$ solution, in all cases after shaking for 30 minutes as described by Jones (2018). Available phosphorus: The soil P was extracted by shaking for 30 minutes at a 1:10 ratio with double acid. The Molybdenum Blue method was followed (Lin *et al*., 2021). Organic carbon (% C): The organic carbon was estimated by the Walkley-Black method, recovery factor (Liu *et al*., 2014). Total nitrogen (% N): The total nitrogen was estimated by the semi-micro Kjeldahl method (Trikilidou *et al*., 2022). Exchangeable cations (ppm): Ca, K and Na were determined using flame photometer and Mg, Cu, Fe, Mn and Zn by atomic absorption spectrophotometer (Albakaa *et al*., 2021).

3.4.3 Effects of Goat Manure and Pearl Millet Stubble Mulch on Growth and Yield of Cowpea

Data were obtained by selecting four cowpea plants randomly in the middle rows after emergence and tagged for data collection and measurements (Olorunwa *et al*., 2023). The types of data collected were quantitative.

Plant Height: a meter ruler was set at the base of main stem, ground level and measurement was taken to the tip (cm) fortnightly.

Number of leaves: The number of borne leaves was counted fortnightly after emergence until cowpea reached full leaf maturity.

Stem girth: a string was used to wrap the stem of tagged cowpea plant circumference and a meter ruler was used to get the stem girth in cm fortnightly up to podding stage.

Number of branches/stems: The numbers of branches/stems per tagged cowpea plants were counted and recorded fortnightly.

Number of flowers: The number of flowers was counted from the tagged cowpea plants weekly after the start of flowering.

Number of pods: The number of pods/cowpea plant was counted fortnightly after the start of pod formation.

Number of grains: Number of grains was counted per pod in tagged cowpea varieties during harvesting.

Seed weight: The grains were harvested and threshed in each experimental unit. Seed weight was weighed in kgs using a weighing balance and translated to ton/ha.

Leaf area

The trifoliate leaf length and width for the four tagged plants in each unit were measured at the central part of the leaf at 50% flowering (Musa & Hassan, 2016). The leaf length and width were obtained for each experimental unit, and the leaf area was calculated using (Musa & Hassan, 2016) as per Equation iii.

$LA = L \times W \times 0.75$……………………………………………..………………Equation iii

Where: LA= leaf area, L is the length, W is the width, and 0.75 is the correction factor

The leaf area index (LAI) was estimated from leaf area per plant (A) divided by land area per plant (p) as in Equation iv

LAI=Leaf perp lant (A)/Land area per plant (P) ………………………...…Equation iv

Where, LAI = leaf area index, A = leaf area per plant (cm^2) and P = land area per plant (cm^2).

3.5 Data Analysis

The survey data collected were entered into a spreadsheet and analyzed using Statistical Package for the Social Sciences (SPSS). The reliability test was conducted by running Cronbach alpha test using command of reliability test in SPSS. Experimental data collected in trials 1 and 2 were recorded and analyzed. The data obtained on soil moisture content, soil chemical properties, growth and yield of cowpea during the experimental time were subjected to analysis of variance

(ANOVA) using SAS to verify the effect of goat manure and pearl millet mulch on growth and yield of cowpeas. Significant means were separated using Least Significance Difference (LSD) at 5% probability level.

Data analysis was done using RCBD in a split plot arrangement model, equation v

$\Upsilon ijk = \mu + \alpha i + \Upsilon k + (\alpha\Upsilon)ik + \beta j + (\alpha\beta)ij + \epsilon ijk$ ………………………..Equation v

Where,

Yijk = The overall observation of the i^{th} level of main plot treatment (cowpea varieties) and the j^{th} level of sub plot treatment (GM, PMM, Control), and k^{th} block.

μ = Overall mean for the treatments (GM, PMM and Control).

αi = The effect of the i^{th} main plot (cowpea varieties)

Υk = The effect of the k^{th} block

$(\alpha\Upsilon)ik$ = The interaction between the i^{th} main plot (cowpea varieties) and the k^{th} block

βj = The effect of the j^{th} sub plot factor (GM, PMM, Control)

$(\alpha\beta)ij$ = The interaction between the i^{th} main plot (cowpea varieties) and the j^{th} sub plot factor (GM, PMM and control)

ϵijk = Random error component

3.6 Ethical Consideration

Çhuka University ethics review committee cleared my research getting an approval on my research proposal (Appendix 1). The research permit (an authorization of research) was obtained from the National Commission of Science, Technology and Innovation (NACOSTI) prior to the start of research (Appendix 2). During the baseline survey, I sought consent from the respondents. Before carrying out an experiment on cowpeas, I obtained a permit from the hosting institution (Appendix 3). In order to contain disease escape and to prevent further infections, collected samples for laboratory study were locked in zip bags. The research procedure steps described in this document were followed with utmost integrity and fidelity. The policy regarding plagiarism was adhered to in the process of data collection, analysis, in document write-up and all the works borrowed from other authors were referenced appropriately.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Demographics and Household Characteristics

4.1.1 Gender

The male respondents were 53%, indicating slightly lower involvement of women in agricultural activities. On the other hand, 47% of the respondents involved in cowpea farming were women, highlighting their significant role compared to men in cowpea production. This could be attributed to cultural norms and gender roles that frequently assign men the task of managing and making decision on subsistence farming activities, including planting, weeding, harvesting and selling cowpeas as source of income. Furthermore, men's involvement in cowpea production can be driven by their role in income generation.

The results of this study are in agreement with those of Sylla *et al*. (2023) who found that the higher male participation in farming is attributed to traditional roles where men are likely to be involved in decision-making related to agricultural production. Sauer *et al*. (2018) observed that men are predominantly engaged in legume cultivation due to their roles in economic value, food security and household welfare. High male involvement in legume farming, some contexts show more balanced or male-dominated participation depending on the crop type, regional practices, and socio-economic factors (Sauer *et al*., 2018). Makinde (2024) found that in some regions, men tend to dominate crops cash, while women focus on household chores. This variation suggests that gender roles are context-specific and influenced by local cultural norms.

4.1.2 Main Occupation

A significant portion of the population, (65%) are farmers engaged in crop and livestock production (Figure 2). Other common occupations include; crop farming, livestock production, and business (15%), crop farming, livestock and casual labour (12%), crop farming, livestock production and employed (4%), crop farming and casual labour (2%) and population practicing only crop production at 2% (Figure 2). This observation highlights the central role that agriculture plays in the livelihoods of the community, with majority (65%) engaging in crop and livestock production. This high level of involvement suggests a rural economy is dependent on mixed farming, as a primary source of income and sustenance for most household. The households surveyed were engaged in a variety of occupations, reflecting a strategy employed by farmers in ASALs to diversify their income sources in the event of failed rainfall or to supplement their farming activities.

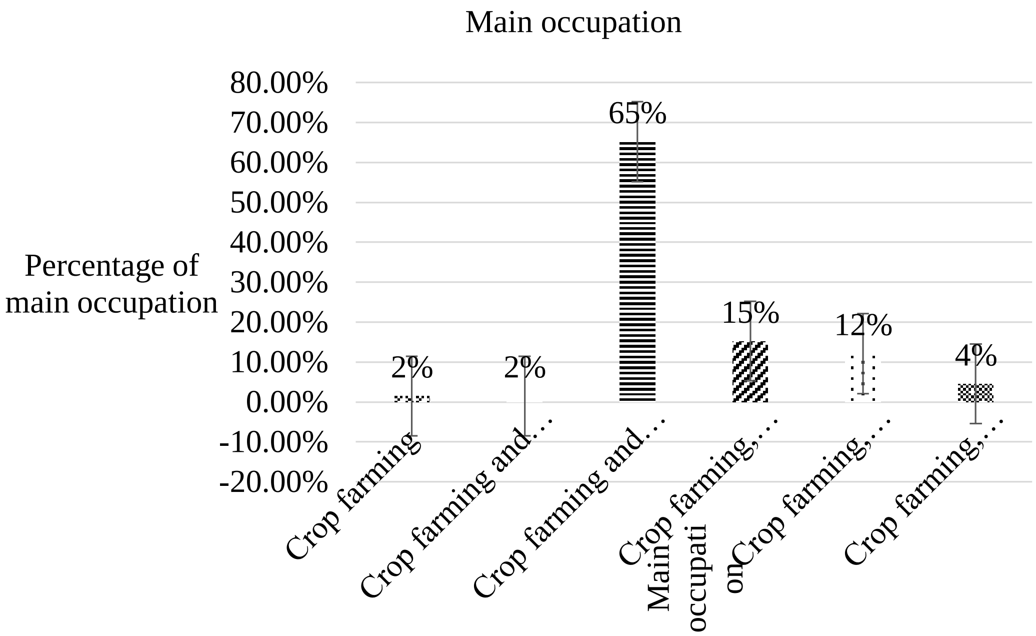

Figure 2: Main occupations of the residents in the study area

The findings indicated a significant portion of the population (65%) are engaged in crop and livestock production. The findings corroborate with those of Mohammed *et al*. (2024), who investigated the integration of livestock and crop production in Ethiopia and reported that the predominance of crop farmers, suggests that agricultural practices serve as the primary livelihood activity for many households. The presence of casual workers suggest that there is a reliance on labor to assist with various farming tasks (Mohammed *et al*., 2024).

Studies have reported a diversified livelihood landscape, just like in Tharaka South, where agriculture is not necessarily the primary source of income for many households. Sankalpa *et al*. (2020) reported in certain communities, off-farm employment, trade, or other non-agricultural activities constitute the main livelihood strategies, with crop and livestock production playing a subsidiary role. Additionally, the relatively small percentage of households solely practicing crop production (2%) indicates that reliance on agriculture alone might be declining, with more households diversifying into other sectors such as business or formal employment as source of livelihood (Alobo & Bignebat, 2017). These findings suggest that while agriculture, including cowpea farming, remains important, it may not be the predominant or sole livelihood activity for many farmers, especially in regions where alternative income sources are more accessible or lucrative.

4.1.3 Farming Practices

The study revealed that 55% of the farmers engaged in mono-cropping, 27% in inter cropping while 18% in crop rotation (Figure 3). This suggests that a significant portion of the community continues to rely on growing a single crop in a given field (mono-cropping). Mono-cropping allow farmers to engage easily with other management practices such as weeding, spraying and harvesting. The highest percentage of the residents used mono-cropping, a practice that is attributed to poor soil fertility, buildup of pests and diseases and ultimately poor crop production. In contrast few residents engage in crop rotation and intercropping demonstrating limited knowledge on the practices that can maximize yield by improving soil fertility and minimizing pest invasion by residents.

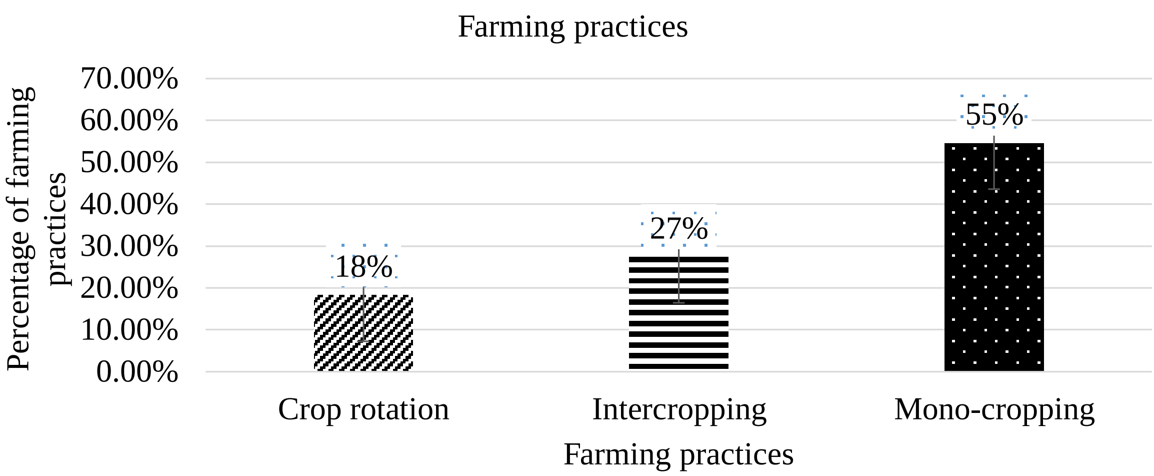

Figure 3: Farming practices in the study area

The observation concurs with those of Ogunwande (2024) who stated that a significant majority of farmers in Nigeria predominantly practiced mono-cropping, which they attributed to limited knowledge of sustainable farming practices and poor soil management, leading to decreased soil fertility and increased pest and disease prevalence. Studies by Kaur *et al*. (2024) found that reliance on mono-cropping was common among smallholder farmers in India, resulting in reduced crop yields and degraded soil health, with limited adoption of crop rotation or intercropping practices. Mono-cropping leads to soil nutrient depletion, increased pest populations, and reduced bio-diversity (Maitra & Ray, 2019). These typically reduce cowpea yields over time. Crop rotation involves alternating different crops in the same field across growing seasons. It is beneficial for reducing soil depletion and controlling pests (Sanfo *et al*., 2023). The low percentage reported in crop rotation indicates a likelihood of poor cowpea yield among the residents. Inter cropping involves growing multiple crops in the same filed simultaneously. This practice improves soil structure, enhance nutrient cycling, and reduce pest pressures due to biodiversity (Maitra & Ray, 2019). The findings indicate that the high percentage of residents practicing mono-cropping probably is linked to environmental and knowledge constraints that hinder sustainable agricultural productivity.

Contrary to these study's findings that mono-cropping predominates among residents due to environmental and knowledge constraints, some research suggests that a growing number of farmers are adopting crop rotation and intercropping practices, driven by increased awareness of sustainable farming methods and the benefits of soil health management. Masombo *et al*. (2020) reported in similar agricultural communities, there is a gradual shift towards diversified cropping systems aimed at enhancing soil fertility, reducing pest and disease pressures, and improving overall yields. Furthermore, the limited engagement in crop rotation and intercropping observed in the current study may reflect a lack of access to information, resources, or training rather than a deliberate choice, implying that with increased extension services and education, adoption of these beneficial practices could improve. Therefore, while mono-cropping remains prevalent in the study area, evidence from other contexts suggests a potential for increased diversification that could positively impact crop productivity and sustainability.

4.1.4 Main Cowpea Varieties

The M66 Variety was the most widely grown, accounting for 44%, followed by KVU 27-1 with 36% (Figure 4). Variety K80 was grown by 14% of the farmers, while Kunde Mboga and Local variety represented 2% and 4%, respectively (Figure 4). M66 was widely preferred followed by KVU 27-1 and K80 probably due to its grain yield, taste, color and cultural preference as per the farmers' feedback. The farmers may also have favored M66 because of its higher yield potential and market demand, making it economically advantageous. Its maturity period aligns well with the local growing season, allowing for optimal harvesting. The varieties may have been locally recognized and available for their suitability to the dry climatic conditions, as they thrive and grow quickly in the prevailing drought conditions.

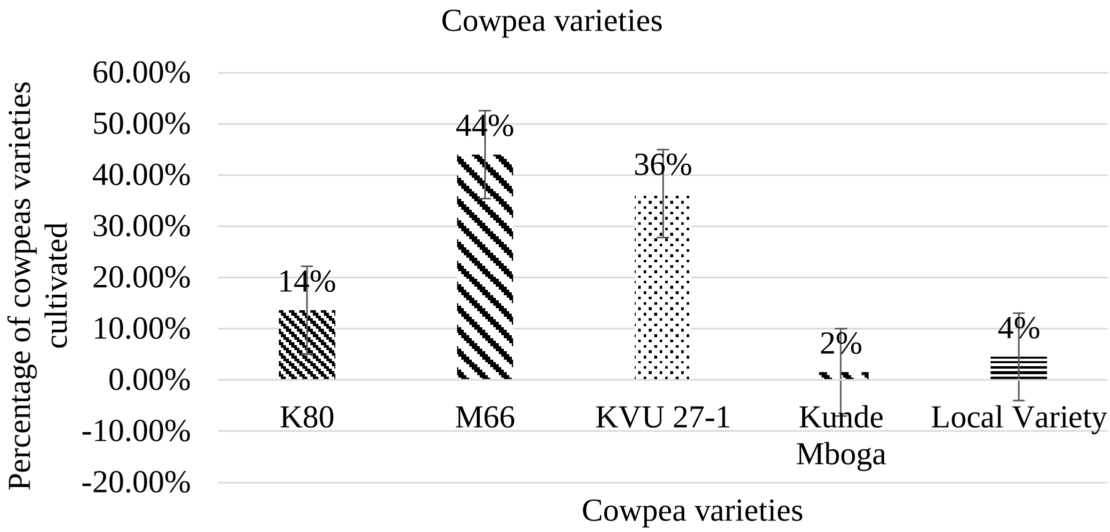

Figure 4: Cowpea varieties grown in Tharaka South

Similar studies in other regions have reported that farmers tend to prefer certain crop varieties based on multiple factors such as grain yield, taste, color, and cultural significance. Studies by Kebede & Bekeko, (2020) similarly observed that the choice of cowpea variety determines the quantity of produce and therefore an important aspect of growth and production of this crop. The results concur with those of Wambua (2021) who identified that the use of high-yielding varieties (HYVs) by the farmers in Kenya, Makueni was influenced by their seasonal earliness, which allowed farmers to optimize production within the limited rainy season.

Studies by Kebede and Bekeko (2020) found that farmers tend to prefer cowpea varieties based on yield potential, pest and disease resistance, drought tolerance, and market demand. In Ethiopia, the M66 variety's popularity aligns with findings that high-yielding and adaptable varieties are widely adopted (Teklemariam *et al*., 2025). Factors such as seed availability, access to extension services, and traditional preferences also shape varietal choices (Ahoudou *et al*., 2025). In some regions, farmers prefer local or indigenous varieties due to taste, cooking qualities, or cultural significance, despite the availability of improved varieties.

4.1.5 Source of Cowpea Seeds

Seeds sourced from previous harvests dominated the distribution, accounting for 62% of the total seed sources (Figure 5). This showed that many farmers relied heavily on their own seed supply for production, indicating a tradition of seed saving to reduce costs associated with purchasing seeds. Seeds obtained from local markets contributed 30% of the total seed source (Figure 5). It shows majority farmers are using seeds from unauthorized sources, hence the need to seek guidance on seed multiplication among farmers which is less expensive. This indicated a significant reliance on local markets for additional planting material, which may be driven by factors such as the availability of certain seed varieties, quality preferences, or economic consideration. This further indicates that most of the producers do not procure cowpea seeds from the advised sources and prefer to use the seeds from the previous harvests; either own or purchased from neighbors or cereal stores.

Seeds sourced from Agro-dealers represented the smallest segment at 8% (Figure 5). This low percentage suggested limited access to Agro-input resources, possibly due to cost, availability, or a lack of awareness among farmers about the benefits of commercial seed sources. This probably lowers their level of technical efficiency because those seeds may not produce as much as those purchased from the advised sources. Hence, the need for an awareness to be procuring certified seeds with vigor and high germination percentage after maybe two seasons.

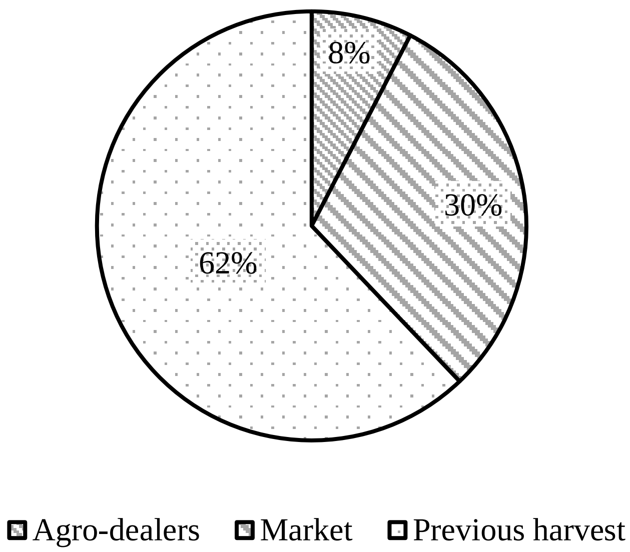

Figure 5: Sources of cowpea seed

Studies conducted by Seay-Fleming (2023) reported that the major provider of seed for cowpea producers was local markets, farmers own saved seeds from prior seasons and borrowing from other farmers. Saka *et al*. (2018) assessed the varietal diversity and production systems of cowpea in South West Nigeria and also stated that cowpea seeds were mainly obtained from local markets. Additionally, Alemu *et al*. (2019) identified the cowpea landrace assortment, and ethnobotany in Eastern and Southwestern parts of Ethiopia had reported that most of the local farmers utilized seeds they had preserved at home. This practice can also reflect a level of self-sufficiency and adaptation to the local environmental conditions (Kebede & Bekeko, 2020).

Distribution of seed sources reflects a strong inclination towards traditional practices (seed saving) supplemented by local market purchases, while reliance on Agro-dealer sources remains minimal. Understanding these patterns can inform interventions aimed at improving seed access and enhancing agricultural productivity in the area. The distribution provides insights into preferred sources of cowpea seeds and reflects the accessibility and availability of seed options to farmers in the region (Breen *et al*., 2024). Many smallholder farmers rely heavily on seed saving due to its low cost, familiarity, and cultural practices (Adem, 2024). For example, in Ethiopia and West Africa, research indicates that seed saving remains the dominant method for maintaining seed quality and ensuring seed availability (Adem, 2024). This practice enhances seed security and reduces dependency on external sources.

Studies by Amoah *et al*. (2023) reported minimal reliance on formal seed systems like seed companies, agro-dealers, or government seed distribution programs, often due to factors such as high costs, limited awareness, or accessibility issues. In Ghana, reliance on local markets and seed saving overshadowed formal seed sources, with less than 20% of farmers obtaining seeds from agro-dealers (Amoah *et al*.,2023).

4.1.6 Percentage of Land Size Under Cowpeas

A substantial (70%) of the farmers dedicated 0.4-0.8 hectares of their land to cowpea (Figure 6). This indicate a strong preference for its cultivation relative to other crops. It implies that cowpea holds a particularly important place in their agricultural practices. This preference could be driven by several factors: cowpea might be a highly profitable crop due to its market demand, or it could be relatively easier and less resource-intensive to cultivate compared to other crops. Additionally, farmers prefer smaller land allocations for cowpea to diversify their crops or to manage risk, ensuring they're not overly dependent on a single crop.

A proportion of 24% of the farmers allocated more than 0.8 hectares to cowpea farming (Figure 6). This highlight a segment of the farming community that prioritizes this crop even further, potentially for commercial production or larger scale operations. Only 6% of farmers allocated less than 0.4 hectare to cowpea cultivation, suggesting that cowpea farming is not a minor undertaking for most residents. This indicate that cowpea is a key crop in the region, reflecting its significance in the local agricultural landscape. The preferences evident in land allocation may influence future agricultural practices, policy decisions, and support programs for crop development in the area.

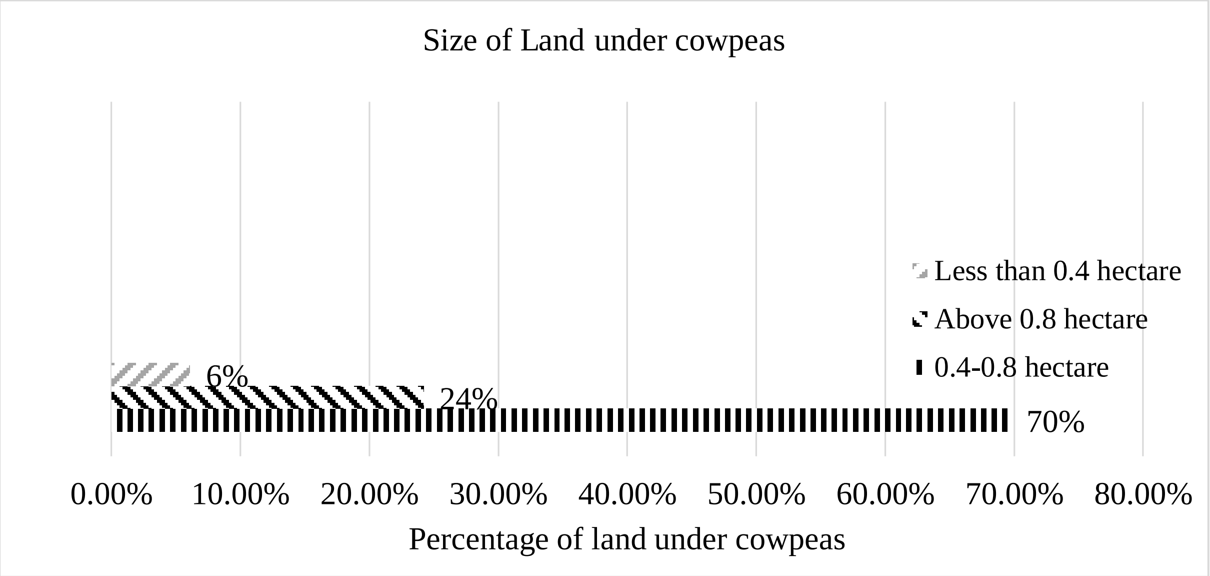

Figure 6: Percentage Land Size under Cowpeas

Study by Nwagboso *et al*. (2024) reported similar findings that cowpea is viewed as a valuable agricultural product, likely due to its economic importance, nutritional value, or market demand and therefore strong preference for its cultivation relative to other crop. Similar findings were reported in Ethiopia and Nigeria, where cowpea is recognized as a vital legume crop that plays a crucial role in ensuring household food security and generating income (Okubazghi, 2024). According to Okubazghi (2024), in these countries, cowpea cultivation is widely practiced among smallholder farmers due to its ability to grow well in diverse environmental conditions and its relatively low input requirements. The crop provides a reliable source of protein and other nutrients, contributing significantly to household diets and nutrition. Additionally, cowpea serves as an important cash crop, enabling farmers to sell surplus produce in local markets, thereby enhancing their income and economic stability (Okubazghi, 2024).

In West Africa, farmers commonly dedicate between 1 and 3 hectares of land to cowpea cultivation, primarily because of its significant economic and nutritional benefits (Nwagboso *et al*., 2024). According to (Nwagboso *et al*., 2024) this land allocation reflects the crop's importance in the livelihoods of smallholder farmers, as cowpea provides a valuable source of income through local and regional markets. Its relatively low input requirements and adaptability to various soil and climate conditions make it an accessible and profitable crop for farmers with limited resources.

Cowpea as a key crop for household food security and income, some studies have reported a relatively limited role for cowpea in certain regions. Borarinwa *et al*. (2022) reported in some parts of East Africa and West Africa, researchers have found that cowpea cultivation is often constrained by factors such as limited access to quality seed, inadequate extension services, and market challenges (Bolarinwa *et al*., 2022). In these areas, farmers tend to allocate smaller plots to cowpea, primarily due to competing land use for staple crops like maize or millet, and a preference for crops with more established market channels or higher yields.

4.1.7 Average Yield of Cowpeas Per hectare

A 36% of respondents reported yields between 0.1-0.2 tonnes/hectare (Figure 7). This yield range indicates that many farmers were achieving moderate productivity, perhaps due to a combination of factors like farming practices, access to inputs, or environmental conditions. A further 30% of respondents reported yields between 0.2-0.3 tonnes/hectares, suggesting that nearly third of the farmers experienced better yields than the lowest range but are still not maximizing potential productivity of cowpea ranging 0.52 to 1.2 tonnes/hectare (Osipitan *et al*., 2021).

The yield ranges of 0.3-0.4 tonnes/hectare and above 0.4 tonnes/hectare were reported by 17% and 11%, respectively (Figure 7), indicating that higher yields were less common among farmers. Lastly, 6% of the respondents reported yields between 0-0.1 tonnes/hectare, highlighting a minority who may be facing significant challenges in cowpea production. While some yields were relatively promising, the distribution indicates a potential for improvement in farming techniques, access to resources, and overall focus on cowpea cultivation.

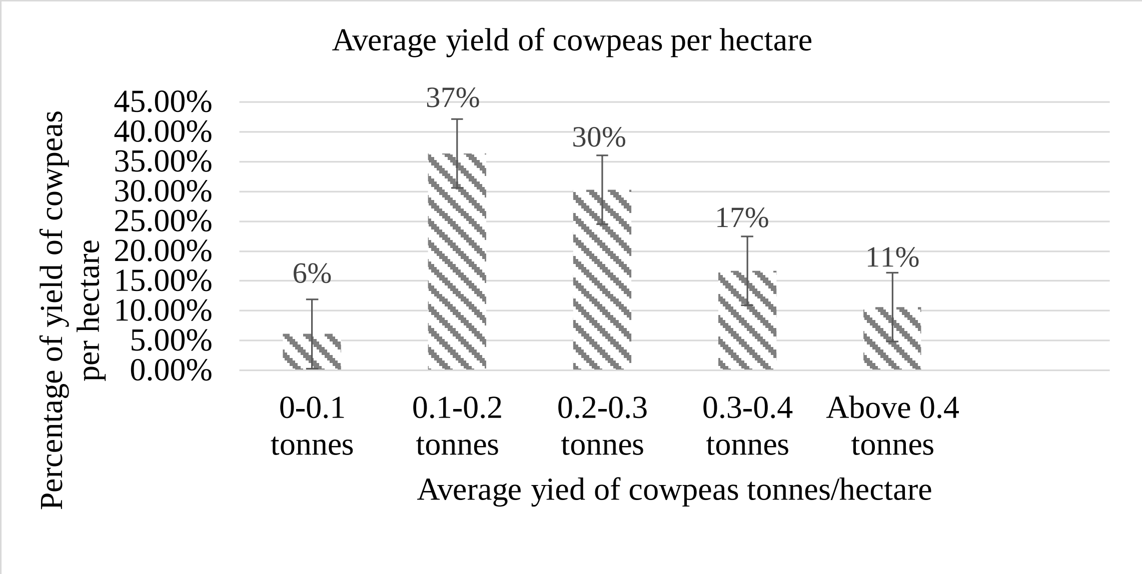

Figure 7: Average Yield of Cowpeas Per Hectare

The variation in yields aligns with Okubazghi (2024) who observed that the variation in maize yields among farmers is significantly influenced by factors such as access to agricultural inputs and the adoption of effective farming practices. Specifically, farmers with better access to essential inputs such as quality seeds, fertilizers, pesticides, and irrigation tend to achieve higher yields. Conversely, those with limited access often experience lower productivity due to suboptimal growth conditions and increased vulnerability to pests and diseases. Additionally, the adoption of improved farming techniques, including crop rotation, proper planting timing, weed control, and pest management, plays a crucial role in maximizing yields.

Study by Nwagboso *et al*. (2024) in Nigeria found that most farmers tend to achieve only moderate yields in cowpea production, primarily because of constraints related to limited resources and environmental challenges. Limited access to quality seeds, fertilizers, and modern farming tools restricts farmers' ability to optimize their crop production. Additionally, many farmers face environmental issues such as poor soil fertility, erratic rainfall, drought conditions, and pest infestations, which negatively impact crop growth and yield potential.

Study by Bolarinwa *et al*. (2022) documented significant increases in cowpea productivity attributed to the adoption of improved seed varieties and advanced farming techniques, highlighting the potential for yield enhancement through targeted interventions. These studies suggest that with appropriate support and technology transfer, cowpea cultivation can achieve higher yields and contribute more effectively to food security (Nwagboso *et al*., 2024). Understanding these yield dynamics is essential for identifying opportunities for agricultural enhancement, including training in best practices, access to improved seed varieties, and sustainable farming techniques**.**

4.1.8 Cowpea Yield Farmer Satisfaction

Majority of respondent were not satisfied with the yield of cowpeas whereby 95.5% were dissatisfied while 4.5% were satisfied with yield. Majority of farmers were not satisfied with yields of cowpea due to moisture stress, pests and diseases. The local climate; dry land, may not be ideal for cowpea cultivation without adopting water saving strategy due to moisture stress and controlling pests and diseases. Studies conducted by Amusa and Ogunkanmi, (2021) reported that targeted training programs significantly increased farmers' awareness of good farming practices that promotes economic benefits, leading to greater interest and adoption. Additionally, research by Okubazghi (2024) demonstrated that the introduction of drought-tolerant cowpea varieties can mitigate moisture stress issues, making cultivation more feasible in dry land areas and might increase yield adoption and satisfaction. These findings suggest that, sowing drought tolerant cowpea seeds and applying organic amendments to the soil are interventions conserves that waters and improves soil fertility improving cowpea yield and increasing satisfaction among farmers.

4.1.9 Challenges Facing Yields of Cowpea

Based on the data collected, it was evident that moisture stress emerged as the most critical and pervasive obstacle, accounting for approximately 65.1% of the total challenges reported by the respondents (Figure 8). This high percentage indicates that a majority of farmers' experience moisture stress, which hinder the proper growth and development of cowpea. Moisture stress affects various physiological processes such as seed germination, vegetative growth, flowering, and pod formation, ultimately leading to reduced yields and harvest quality. Approximately 30.1% of farmers face soil degradation (Figure 8). This leads to low soil fertility and results in slow, stunted growth of cowpeas due to limited supply of macro and micro nutrients. Diseases, pests, and the use of uncertified seeds were minor challenges, affecting only 1.6% of production (Figure 8). These issues contribute to reduced quality and quantity of cowpeas, as pest and disease infestations interfere with their growth and development.

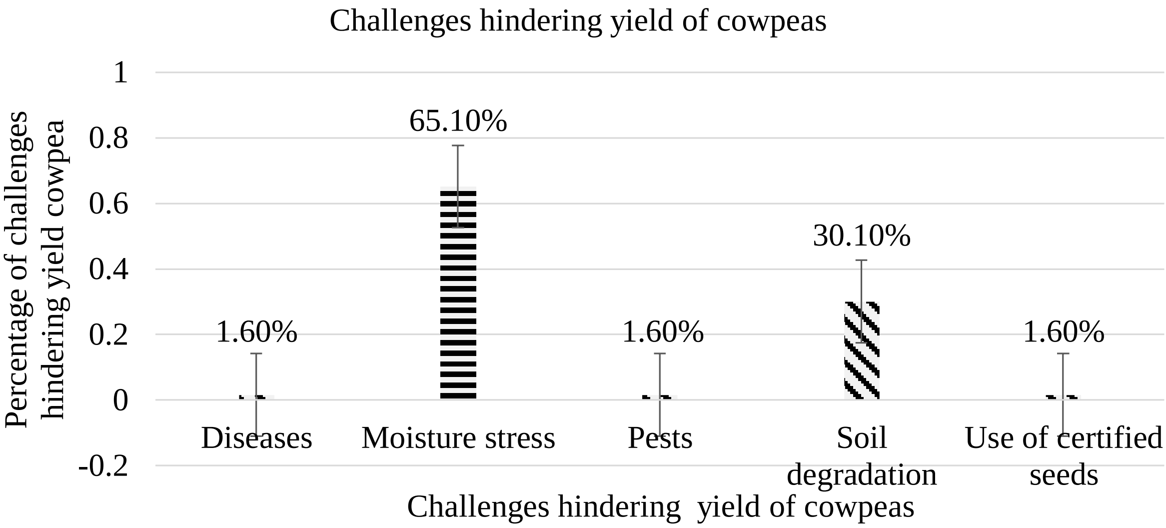

Figure 8: Challenges Hindering Optimum Yield of Cowpea

The survey findings correspond with those of Omomowo and Babalola (2021) who identified moisture stress as the primary and most significant challenge hindering both the production and overall growth of cowpeas. According to their findings, inadequate water availability during critical stages of cowpea development severely limits the plant's ability to grow optimally, resulting in reduced yields and compromised crop quality. Following moisture stress, soil degradation was identified as another substantial challenge, representing about 30.1% of the difficulties encountered by farmers. Soil degradation encompasses a broad spectrum of issues including nutrient depletion, erosion, poor soil structure, and decline in soil fertility (Kebede & Bekeko, 2020). These factors collectively reduce the soil's capacity to support healthy cowpea cultivation, thereby limiting potential yields. Addressing soil degradation requires implementing effective soil conservation measures, improving soil fertility through appropriate fertilization practices, and adopting sustainable land management techniques.

Environmental and soil-related issues, biotic factors such as diseases were also noted as significant, although they contributed a relatively small proportion approximately 1.6%. The occurrence of cowpea diseases can lead to severe plant health problems, resulting in stunted growth, poor pod development, and ultimately, reduced harvests if not properly managed (Mahesha *et al*., 2022). Similarly, the use of uncertified seeds was reported as a challenge, also accounting for 1.6% of the constraints. The reliance on uncertified seeds often results in poor germination rates, weak plant vigor, and increased susceptibility to pests and diseases, which collectively contribute to lower yields (Afzal *et al*., 2019). These challenges, individually and collectively, pose substantial barriers to achieving the desired levels of cowpea productivity.

The survey findings illustrate the dominance of moisture stress as the primary constraint, followed by soil degradation, with biotic and seed quality issues playing comparatively smaller but still significant roles. The findings agree with those of Omomowo and Babalola, (2021) who found that moisture stress as the predominant factor limiting cowpea production. Hajam and Kumar (2022) on the contrary found that pest attacks, particularly by cowpea bruchid and aphids, significantly reduced seed yield and quality in Nigeria, sometimes more than drought conditions. The difference may depend with environmental variability and management practices adopted different countries.

4.1.10 Strategies used by Farmers to Improve Cowpea Yield

The respondents proposed a variety of strategies aimed at improving cowpea yields, with the most widely recommended being the application of organic fertilizers combined with the use of crop residues. This approach was endorsed by a significant majority, accounting for approximately 67% of the respondents (Figure 9). This shows integrating organic fertilization techniques with the utilization of crop residues could play a crucial role in enhancing soil fertility, promoting healthier plant growth, and ultimately increasing cowpea productivity. Smaller segment of the respondents suggested alternative or supplementary approaches. For instance, about 9%, respondents, recommended a combination that includes the use of certified seeds along with the application of organic fertilizers and crop residues due to their vigor.

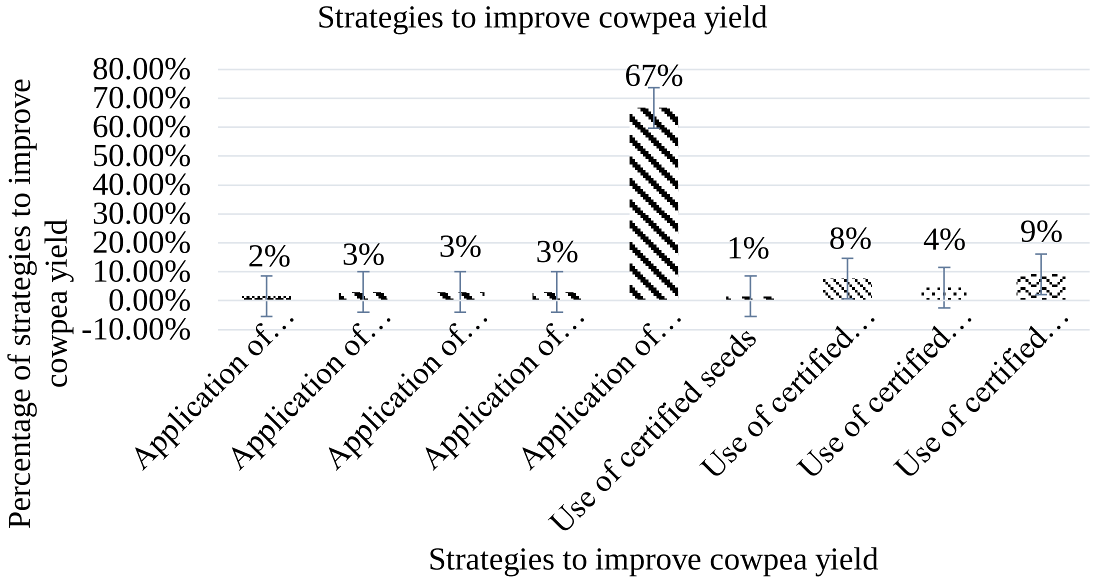

Figure 9: Strategies to that can Improve Cowpea Yield

Integrating organic fertilizer and crop residues survey findings align with the study conducted by (Wato *et al*., 2024) in Ethiopia, which also highlighted the significant potential of integrating organic fertilization techniques with crop residue utilization to improve soil health, support robust plant growth, and ultimately boost cowpea yields. This approach has been reported to underscores the importance of starting with high-quality, certified planting material while simultaneously enriching the soil through organic amendments and crop residue management to boost yields (Verma *et al*., 2024). Furthermore, approximately 8% of the respondents, emphasized the use of certified seeds in conjunction with organic fertilizer application as a key strategy. This indicates a recognition of the importance of using improved seed varieties alongside soil fertility management practices to achieve better crop performance.

A smaller group, comprising of the 4% respondents, advocated for an integrated approach that involves the use of certified seeds, previous crop residues, and both organic and inorganic fertilizers. This comprehensive strategy reflects an understanding of the benefits of nutrient supplementation through inorganic fertilizers, and organic amendments to optimize cowpea production. All these proposed strategies collectively highlighted the diverse approaches necessary to enhance cowpea yields.

Study conducted by Liu *et al*. (2021) stated that in certain semi-arid regions, the application of organic fertilizers and crop residues did not significantly improve soil nutrient levels or crop yields due to rapid organic matter decomposition and nutrient losses. Similarly, Kumar *et al*. (2020) observed that the effectiveness of organic amendments varied widely depending on soil type and management practices, with some cases showing minimal or no yield increases. The contrasting findings suggest that the benefits of organic fertilization and crop residues may be context-dependent and influenced by local environmental conditions.

4.1.11 Application of Previous Crop Residues in the Farm and its Benefits

In the study, only 30% of farmers incorporated crop residues into their farming practices, whereas a significant 70% did not use them. This significant gap suggests that most farmers may lack awareness or understanding of the benefits that crop residues can offer, such as conserving soil moisture, preventing erosion, and enriching the soil with vital nutrients. The low adoption rate indicates a missed opportunity for improving soil health and crop productivity through sustainable residue management practices.

Studies by Obahiagbon and Ogwu (2024) reported similar findings that, limited adoption of crop residue management suggests that many farmers may not fully recognize the benefits these residues can provide in enhancing crop productivity and soil health. Consequently, this indicates a need for increased education and awareness campaigns to inform farmers about the critical role crop residues play in sustainable farming systems, especially in maximizing crop yields through improved moisture retention and nutrient input (Sarkar *et al*., 2020).

Studies have reported contrary to the observation, of higher adoption rates of crop residue management among farmers, suggesting that awareness and utilization may be more widespread in certain regions (Bana *et al*., 2023). In parts of sub-Saharan Africa, approximately 60-70% of farmers actively incorporate crop residues into their farming systems, primarily due to targeted extension services and farmer training programs (Harmon, 2022). Studies by Liu *et al*. (2021) observed that in some Asian agricultural communities, majority of farmers recognize the benefits of crop residues for moisture conservation and soil fertility, leading to high adoption rates exceeding 50%. These findings imply that the low usage rate of 30% observed in this context could be specific to certain local factors, such as limited access to information, cultural practices, or resource constraints, rather than a general trend across different agricultural regions (Liu *et al*., 2021).

The respondents who used crop residues identified several benefits from their application, including improved moisture retention at 80%, soil conservation at 10%, and increased organic matter in the soil at 10% (Figure 10).

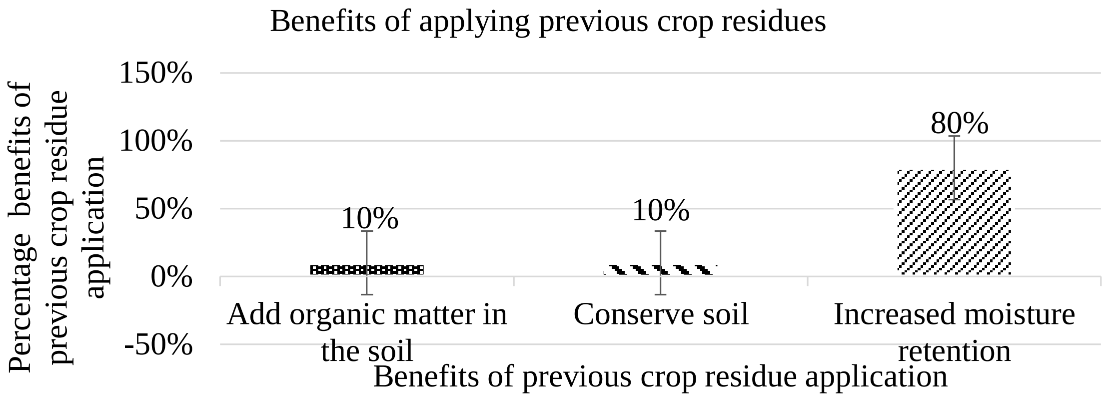

Figure 10: Benefits of Applying Previous Crop Residues

The high percentage of respondents citing application of previous crop residues retains moisture as a primary benefit concurring with studies conducted by Kirimi (2019) who highlights that crop residues act as a natural mulch layer, reducing evaporation and helping the soil retain water more effectively. By covering the soil surface, residues create a barrier against direct sunlight and wind, which decreases water loss and maintains higher soil moisture levels, especially during dry periods

The respondents who did not use previous crop residues, 43.5% reported feeding them directly to livestock, 34.8% burned the residues and also fed them to livestock, 13% sold the residues while feeding some to livestock, and 8.7% solely burned the residues (Figure 11). These results concurs with those of Bhandari, (2019), who found that feeding crop residues to livestock is a common practice in many farming communities because it provides a readily available source of fodder, especially during dry seasons when other feed options are scarce. Unlike other studies reporting feeding of crop residues to livestock, my study suggests the use of available crop residues of pearl millet in soil and water conservation in ASALs.

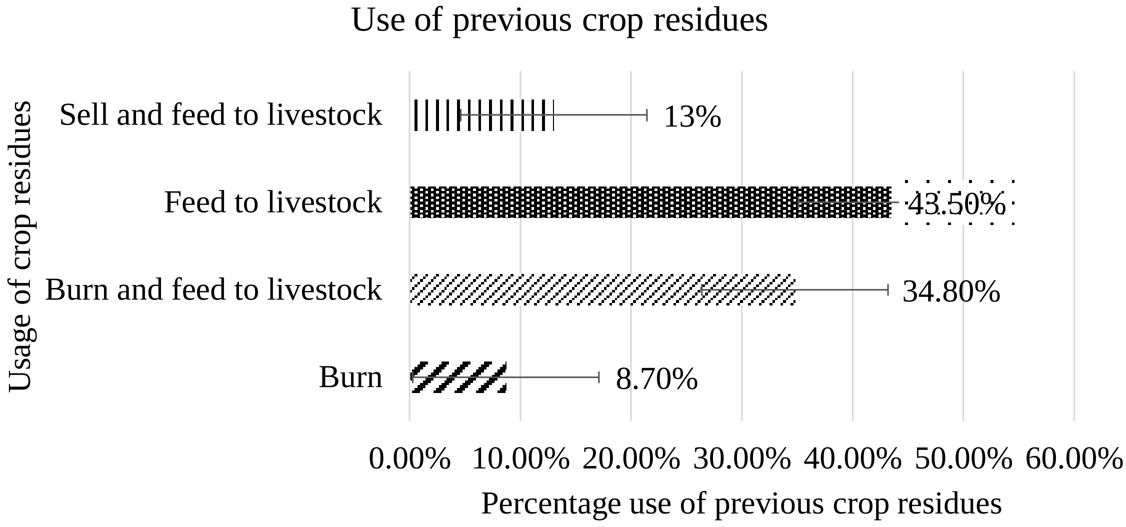

Figure 11: Use of Previous Crop Residues

Burning crop residues, on the other hand, is often done to quickly clear fields for subsequent planting, control pests or diseases, or remove leftover crop material that may hinder planting operations (Bhuvaneshwari *et al*., 2019). However, burning also leads to loss of organic matter and nutrients, reducing soil fertility. The practice of selling residues might be driven by economic needs, where farmers see immediate financial benefits. Some farmers may burn residues to save time and effort, especially if they lack the resources or knowledge to utilize crop residues effectively for soil health or livestock feed (Duncan *et al*., 2016).

Studies by Abo Bakr *et al*. (2024) on the utilization and alternative uses of agriculture residues in Egypt highlighted the promising role that agricultural residues play in livestock nutrition and farm sustainability. Agricultural residues, including crop leftovers like straw, stalks, husks, and other waste from farming activities, are abundant and often underutilized resources. Their potential as feed stems from their availability and the possibility to convert them into nutritious, digestible feed options for livestock, especially in regions where conventional feedstuffs are scarce or expensive (Abo Bakr *et al*., 2024). The relatively high percentage of farmers feeding residues to livestock reflects the dual purpose of crop residues as both a resource for animal feed and a means of managing crop leftovers.

The significant proportion burning residues indicates a preference for quick field clearance or a lack of awareness or resources to adopt alternative residue management practices (Duncan *et al*., 2016). Understanding these motivations helps in designing interventions to promote more sustainable residue management strategies that balance crop production, soil health, and livestock needs.

4.1.12 Livestock Kept and Use of Manure

Goats were the most commonly kept livestock, accounting for 62%, followed by chickens at 20%, cattle at 17%, and pigs at 1% (Figure 12). The high percentage of goats kept in the study area was attributed to their high adaption to various environmental conditions, less space requirement, and are more resistant to diseases compared to other livestock. They also have a lower initial investment and maintenance cost, making them accessible for smallholder farmers. The high percentage of goats that account for 62% concurs with Nair *et al*. (2021) who considers the goat rearing in regions with warm, humid climates typical of South Asia, Southeast Asia, Africa, and parts of Latin America. Goats' have resilience and advantages over other livestock in these climates, which are often characterized by high temperatures, humidity, and variable feed and water availability leading their high prevalence (Nair *et al*., 2021). The goats are also preferred in these communities because they are valuable for their meat, milk, and hides, providing multiple sources of income and nutrition.

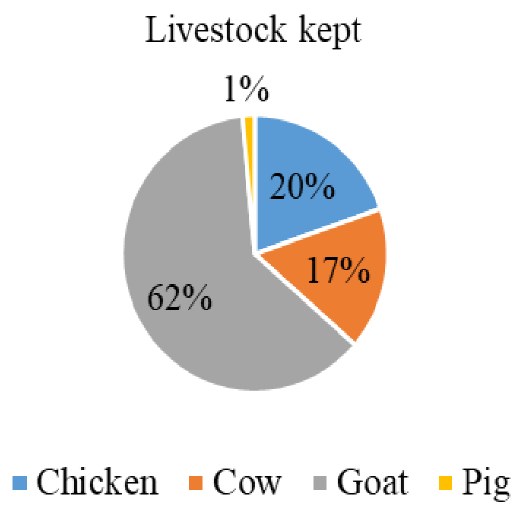

Figure 12: Livestock Kept

Chickens rearing are popular due to their ease of management, quick reproductive cycle, and relatively low cost, making them suitable for household-level production (Alemayehu *et al*., 2018). Cattle may be less prevalent due to higher maintenance costs, space requirements, or cultural preferences (Charlton & Rutter, 2017). The low percentage of pig ownership could be influenced by cultural or religious beliefs, as some communities may have taboos against pig rearing, or it could be due to environmental factors that make pig farming less suitable in the area (Keray *et al*., 2024).Overall, the higher prevalence of goats reflects their suitability to local environmental conditions, economic affordability, and multipurpose use, which makes them the preferred livestock among the respondents.

Goats were the most prevalent livestock due to their adaptability and multipurpose use, some studies have suggested that in certain regions, cattle or poultry may be more dominant depending on local conditions (Anyona *et al*., 2023). In areas with better grazing land and water availability, cattle might be more common because of their higher productivity in terms of milk and meat (Nanganga & Safalaoh, 2020). Similarly, in communities where cultural preferences favor poultry for quick income and easy management, chickens could surpass goats in prevalence (Anyona *et al*., 2023).

The majority of respondents (70%) did not use manure from their livestock, whereas 30% applied manure from their farms (Figure 13). This low adoption rate suggests that many farmers are either unaware of the benefits of manure or face practical, economic, and cultural barriers that discourage its use. Factors such as the labor-intensive process of collection, storage challenges, odor issues, or concerns about disease transmission may influence farmers' decisions. Additionally, some farmers might prefer chemical fertilizers due to perceived immediacy, ease of use, or traditional practices. These findings agree with Ndambi *et al*. (2019) who found that many farmers may lack awareness or knowledge about the benefits of using manure as a natural fertilizer, leading to its underutilization.

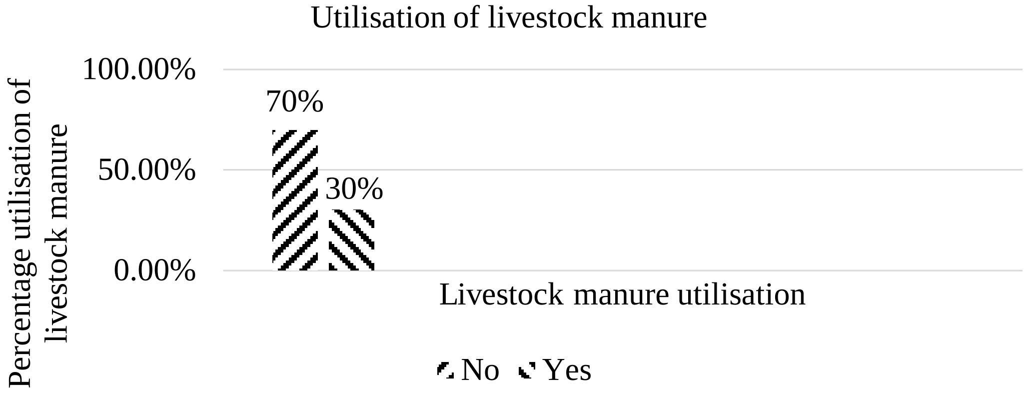

Figure 13: Percentage of Respondent Utilizing Livestock Manure

Some farmers might face challenges related to the collection, storage, or application of manure, which could discourage its use. Cultural practices or traditional beliefs may also influence the decision, with some farmers preferring chemical fertilizers or other methods of soil improvement (Liu *et al*., 2018). Overall, the low adoption rate of manure use suggests a need for increased education, improved manure management practices, and access to resources to promote sustainable farming methods among the farmers. However, some studies have found that farmers in certain regions already possess sufficient knowledge about the benefits of manure but still choose not to use it. The research by Ngoma *et al*. (2018) indicated that despite awareness of manure's advantages, farmers may refrain from utilization due to practical challenges such as labor intensity, odor issues, or concerns about disease transmission. Additionally, economic considerations, like the costs associated with manure collection and storage might outweigh perceived benefits, leading farmers to prefer chemical fertilizers or other soil amendments.

Cultural practices or traditional beliefs in some contexts may also influence farmers' decisions, making them skeptical of manure's effectiveness or desirability (Ngoma *et al*., 2018). Therefore, the low adoption rate might not solely stem from a lack of knowledge but could be driven by these practical, economic, or cultural factors. Addressing these barriers requires tailored interventions that go beyond education alone, focusing on improving manure handling techniques, reducing associated costs, and aligning to farmers' preferences and beliefs.

In the study, 90% of the respondents are aware of the benefits of manure application, particularly in terms of adding organic matter to the soil and enhancing soil fertility. Only 10% recognized that manure also helps improve water infiltration and retention (Figure 14).

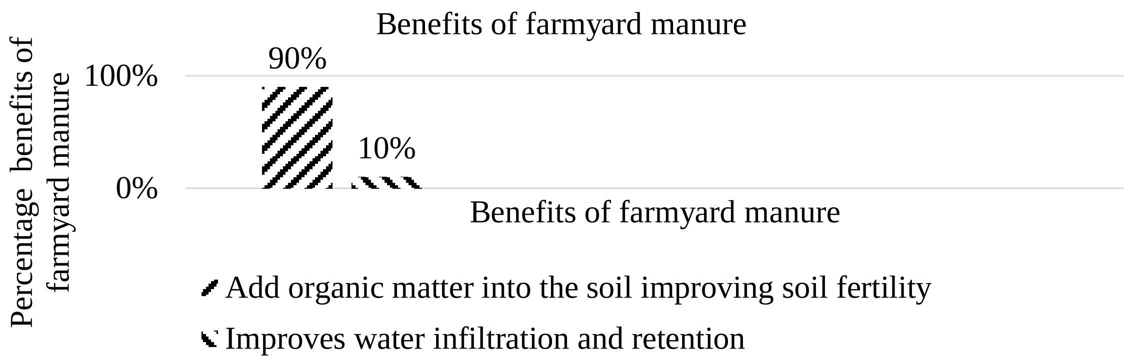

Figure 14: Benefits of Farmyard manure

This disparity in knowledge could be due to several factors. The high awareness of manure's role in enriching soil fertility suggests that many farmers had received education or had practical experience emphasizing its importance for crop growth. Extension services, agricultural training programs, or traditional knowledge might have focused more on manure's fertilization benefits, making this aspect more widely known (Jagisso *et al*., 2019). Fewer farmers on other hand were aware of manure's impact on water conservation because this benefit is less emphasized in training or agricultural discussions. Water retention and infiltration are more technical aspects of soil health, which might require more specialized knowledge or scientific understanding that not all farmers have access to. Additionally, cultural perceptions or misconceptions might lead farmers to overlook manure's role in water conservation.

The overall picture indicates that while most farmers recognize the importance of manure in soil fertility, there is less awareness of its benefits related to water management, highlighting a potential area for education and extension efforts to promote a comprehensive understanding of manure's multiple advantages.

4.1.13 Soil Conservation Measures

In the study, 21.2% of farmers practiced soil conservation measures while 78.8% did not. Majority farmers not practicing soil conservation measures: means probably farmers lacked awareness or knowledge about the long-term benefits of soil conservation practices, or there may be limited access to resources, training, and support needed to implement such measures. A study by Ranjan *et al*. (2019) stated that implementing soil conservation techniques often requires initial investments which some farmers may not afford. Economic limitations can discourage farmers from adopting practices that do not promise immediate benefits (Ranjan *et al*., 2019). Jin *et al*. (2022) found that cultural beliefs and traditional farming methods may also influence farmers' willingness to adopt new practices resisting change. Half of the farmers (50%) suggested conservation agriculture can improve cowpea yield, followed by specific practices such as maintaining permanent soil cover with 29%. Terracing 14%, and contour farming 7% as soil conservation measures (Figure 15).

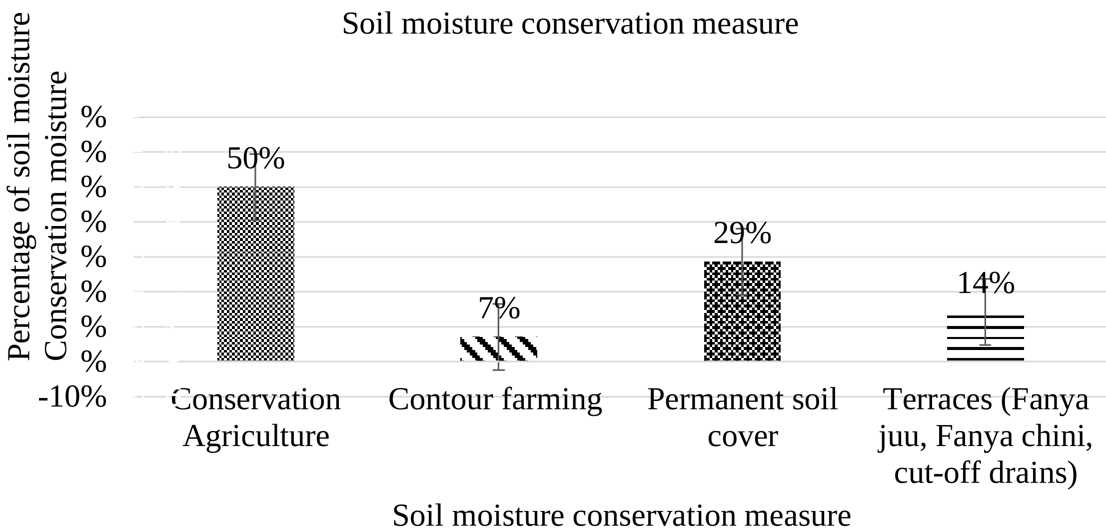

Figure 15: Soil Moisture Conservation Measure

The relatively higher adoption rate of conservation agriculture at 50% recommendation by farmers was probably attributed to its perceived benefits, such as improving soil health, reducing erosion, and increasing crop yields. Conservation agriculture often involves minimal soil disturbance by ripping and use of planting basins, crop rotation, and maintaining soil cover, practices that are generally understood to be beneficial for sustainable farming.

Lower adoption rates of permanent soil cover, terracing, and contour farming however, suggest several underlying factors. First, these practices often require more resources, labor, and technical knowledge to implement effectively. Terracing and contour farming involve significant land modifications and may require substantial initial investment and technical skills, which can be barriers for smallholder farmers with limited resources (Ranjan *et al*., 2019). Second, awareness and understanding of these practices may be limited among farmers, especially if extension services are inadequate or if there is a lack of training programs that demonstrate the benefits and proper implementation methods (Jin *et al*., 2022). Without proper knowledge, farmers might be hesitant to adopt practices that they perceive as complicated or risky.

Farmers recognize the environmental and productivity benefits of conservation agriculture, its actual implementation is limited by various barriers (Sennuga, 2019). Hailu and Teshome, (2022) observed that in Ethiopia, while farmers expressed awareness of conservation agriculture practices such as minimal soil disturbance and crop rotation, actual adoption remained low, at around 20%. The primary reasons included limited access to necessary equipment, labor shortages, and a lack of technical knowledge. Similarly, the study conducted by Sennuga (2019) noted in Nigeria although farmers appreciated the potential benefits of conservation practices, only a small proportion actively adopted them due to financial constraints and the perceived complexity of the techniques.

4.2 Effects of Goat Manure and Pearl Millet Stubble Mulch on Soil Moisture Levels under Dry Land Conditions

The application of goat manure and pearl millet stubble mulch had significant ($p < 0.05$) effect on soil moisture contents (Table 2). There was a significant ($p < 0.05$) effect of applying goat manure and pearl millet stubble mulch on soil moisture content compared to the control treatments without any inputs (Appendix 6). In both trials, the mean soil moisture contents across replicates showed significant differences ($p<0.05$) across different days (Table 2). The results indicated a high to lowest moisture content on pearl millet mulch (PMM), goat manure (GM) and control respectively in both trials I and II (Table 2). The soil moisture levels increased in the following order from; control; goat manure; pearl millet mulch across three cowpea varieties in both trials. Trial I and II had the highest soil moisture of 25.77% and 28.03% at 21 and 7 DAS with application of pearl millet mulch for M66 and K80 variety, respectively.

Table 2: Effects of Goat Manure and Pearl Millet Mulch on Soil Moisture Status (%) under Cowpea

Trial	Cowpea Variety	Treatment	Initial	SMC7DAS	SMC14DAS	SMC21DAS	SMC28DAS	SMC35DAS	SMC42DAS	SMC49DAS
I	K80	CONT	11.17^{a}	23.53^{a}	16.77^{a}	23.53^{a}	14.33^{a}	13.83^{ab}	13.57^{ab}	12.47^{a}
		GM	13.87^{abc}	24.70^{abcde}	17.73^{a}	24.70^{abcde}	15.43^{ab}	14.13^{abc}	13.83^{abc}	13.33^{abcd}
		PMM	17.33^{d}	25.53^{cdef}	19.53^{b}	25.53^{e}	16.60^{bc}	15.90^{def}	15.27^{bcdef}	14.37^{bcde}
	KVU 27-1	CONT	11.50^{a}	23.70^{a}	16.63^{a}	23.80^{abcd}	14.13^{a}	13.50^{a}	13.20^{a}	12.73^{ab}
		GM	12.50^{ab}	24.50^{abc}	17.37^{a}	24.50^{abcde}	15.43^{a}	15.03^{bcde}	14.73^{abcd}	14.07^{abcde}
		PMM	15.23^{bcd}	25.27^{bcde}	19.23^{b}	25.27^{bcde}	16.80^{bc}	16.40^{ef}	15.77^{cde}	14.87^{cde}
	M66	CONT	11.50^{a}	23.87^{ab}	16.77^{a}	23.87^{abcd}	14.23^{a}	14.43^{abcd}	13.40^{ab}	12.77^{ab}
		GM	13.87^{abc}	24.67^{abcd}	17.63^{a}	24.33^{abcde}	15.73^{abc}	14.97^{abcde}	14.40^{abc}	13.23^{abc}
		PMM	16.73^{cd}	25.60^{cdef}	19.30^{b}	25.77^{e}	17.27^{c}	16.37^{ef}	15.40^{bcdef}	14.80^{cde}
II	K80	CONT	12.23^{ab}	26.17^{defg}	23.63^{c}	23.73^{abc}	23.53^{d}	15.47^{cdef}	14.17^{abc}	12.77^{ab}
		GM	12.57^{ab}	27.07^{fgh}	25.03^{de}	25.07^{abcde}	24.70^{def}	16.07^{ef}	14.83^{abcd}	14.80^{cde}
		PMM	12.63^{ab}	28.03^{h}	25.53^{e}	25.30^{cde}	25.53^{f}	18.00^{gh}	15.77^{cdef}	15.00^{cde}
	KVU 27-1	CONT	12.27^{ab}	26.23^{efg}	23.87^{c}	23.83^{abcd}	23.80^{de}	16.30^{ef}	15.10^{abcde}	12.80^{ab}
		GM	12.63^{ab}	26.93^{fgh}	25.03^{de}	25.00^{abcde}	24.50^{def}	18.27^{h}	16.53^{def}	14.10^{abcde}
		PMM	12.77^{ab}	27.80^{h}	25.73^{e}	25.20^{bcde}	25.27^{ef}	19.23^{hi}	16.60^{def}	15.37^{e}
	M66	CONT	12.43^{ab}	26.23^{efg}	23.93^{cd}	23.67^{ab}	23.87^{de}	16.67^{fg}	14.63^{abcd}	13.33^{abcd}
		GM	12.70^{ab}	27.37^{gh}	25.03^{de}	25.40^{de}	24.57^{def}	19.40^{hi}	17.00^{ef}	15.07^{cde}
		PMM	12.63^{ab}	27.87^{h}	25.63^{e}	25.67^{e}	25.53^{f}	20.23^{i}	17.27^{f}	15.17^{de}
		Mean	13.14	25.837	21.356	24.676	20.070	16.344	15.081	13.946
		CV (%)	4.1	1.8	1.7	2.0	2.5	2.9	4.1	7.7
		$LSD_{(0.05)}$	1.681	0.7886	0.5916	0.827	0.8338	0.5513	1.0343	0.9448
		P-Value	-	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Legend: CONT-control, GM-Goat Manure, PMM-Pearl Millet Mulch, SMC-Soil Moisture Content and DAS-Days after Sowing. Means with the same letters within the same column are not significantly different ($P<0.05$).

Pearl millet mulch recorded high soil moisture contents of 16.7%, 25.60%, 19.53%, 25.77%, 17.27%, 16.40%, 15.77%, and 14.87%, and goat manure showed 13.8%, 24.67%, 17.73%, 24.70%, 15.73%, 15.03%, 14.73%, and 14.07% and control had 11.50%, 23.87%, 16.77%, 23.87%, 14.33%, 14.43%, 13.57%, and 12.77% at initial, 7, 14, 21, 28, 35, 42, and 49 days after sowing (DAS) in trial I under M66, K80, and KVU 27-1 respectively (Table 2).

Pearl millet mulch recorded; 12.7%, 28.03%, 25.73%, 25.67%, 25.53%, 20.23%, 17.27% and 15.37%, goat manure had; 12.70%, 27.37%, 25.40%, 24.70%, 19.40%, 17.00% and 15.07% while control had 12.50%, 26.23%, 23.93%, 23.83%, 23.87%, 16.67%, 15.10% and 13.33% at initiation, 7, 14, 21, 28, 35, 42 and 49 DAS respectively in trial II (Table 2).

This suggests that the use of pearl millet mulch and goat manure helps retain soil moisture. Specifically, the pearl millet mulch appears to create a protective layer that reduces evaporation, maintaining higher soil moisture levels in M66, KVU 27-1 and K80. Also pearl millet mulch intercepts the raindrops increasing chances of water infiltration and water retention. Goat manure, while beneficial for soil fertility, may also contribute to moisture retention by improving soil structure and organic matter content through improvement of aggregate stability improving water infiltration and retention. The control, lacking any mulch or organic amendment, likely experiences faster moisture loss due to direct exposure to environmental conditions. M66 cowpea variety responded well to soil moisture conservation probably due to its ground cover through canopy and spreading nature that creates a microclimate with minimized evapotranspiration, followed by K80 and KVU 27-1. Another probable reason is the deep taproot system and latera roots that extract water from soil layers. It also has small, thick and waxy leaves minimizing water loss.

These findings align with studies conducted by Yadav *et al*. (2022) that demonstrated the beneficial effects of pearl millet mulch on soil microclimate, particularly its ability to reduce wind velocity and soil temperature, which significantly enhances water retention in dryland and semi-arid agricultural systems. Pearl millet mulch forms a physical barrier on the soil surface that interrupts the movement of wind across the soil. This reduction in wind speed is critical because wind-driven evaporation is a major pathway for water loss in dry environments. By decreasing wind velocity at the soil surface, the mulch minimizes the mechanical removal of moisture, thereby conserving soil water resources (Yadav *et al*., 2022).

Studies by Sharma (2018), also demonstrated that surface mulching significantly decreases wind speed and evaporation. Additionally, Rana & Roy (2024) highlighted that organic amendments like goat manure improve soil structure and water-holding capacity over time. Goat manure contributes organic matter to the soil, which improves its physical properties by increasing porosity, aggregate stability, and aeration (Rana & Roy, 2024). Hence the structural improvements by pearl millet mulch facilitated better infiltration of water during rainfall or irrigation and reduce surface runoff, allowing more water to penetrate and be retained within the soil profile.

Pearl millet stubble mulch acts as a shelter belt, effectively reducing wind velocity at the soil surface (Taak *et al*., 2021). According to Sharma, (2018) this reduction in wind speed by approximately 30% significantly decreases soil water evaporation. This mechanism is crucial because wind-driven evaporation is a major pathway for water loss in dry and semi-arid environments (Sharma, 2018). The mulch also shades the soil surface, lowering temperatures and further reducing the potential for water evaporation, as supported by (El-Beltagi *et al*., 2022) who highlighted that surface mulch can minimize soil surface temperature fluctuations. In contrast, goat manure, while beneficial for soil fertility and organic matter content, does not form a physical barrier against wind or temperature fluctuations. Therefore, its impact on soil moisture retention is less pronounced compared to mulch. The mulch's ability to act as a sponge and reduce surface runoff by 43% (Singh, 2023).

The findings emphasize the importance of mulching as an effective soil moisture conservation strategy, particularly in arid and semi-arid regions. The physical barrier provided by pearl millet stubble mulch not only reduces evaporation but also stabilizes soil conditions, thereby promoting healthier plant growth and potentially increasing crop yields. Based on the finding of this study goat manure underscores that while organic amendments improve soil health, physical mulching plays a critical role in water conservation, which is vital under drought-prone conditions.

Studies support the positive effects of pearl millet mulch on soil moisture retention, some researchers have reported contrary findings. For instance, in certain environments, the effectiveness of mulching can vary depending on factors such as mulch thickness, soil type, and climate conditions. Some studies suggest that excessive or poorly managed mulching may lead to reduced soil aeration or hinder seed germination, particularly if the mulch layer is too thick, which could potentially limit water infiltration or create conditions conducive to pest and disease development (El-Beltagi *et al*., 2022). Studies by (Demo & Asefa Bogale, 2024) observed that mulch could create a microhabitat that favors weed proliferation, which may compete with crops for moisture and nutrients, thereby offsetting some of the moisture conservation benefits.

In regions with high rainfall, mulch may sometimes lead to increased surface runoff if not properly managed, reducing water retention rather than enhancing it. El-Beltagi *et al*. (2022) reported that in such conditions, mulching can sometimes result in water logging or increased soil erosion if the mulch layer impedes water infiltration or if the soil is already saturated. Furthermore, the type and composition of mulch matter significantly. Although the majority of research supports the benefits of pearl millet mulch for soil moisture conservation, there are contexts and conditions under which mulching may have neutral or even adverse effects (Demo & Asefa Bogale, 2024). These findings highlight the importance of tailoring mulching practices to specific environmental and soil conditions to maximize benefits.

The results revealed use of goat manure had higher percentage of soil moisture content after pearl millet mulch with an application rate of 8.75 tonnes per hectare. Goat manure contains organic matter that improves the soil structure. The results of this study are supported by the findings of Rana & Roy, (2024) who reported that the soil structure manages or modulates the distribution, movement, and retention of water, solutes, and gases. Similarly, the study of (Mkomwa *et al*., 2023) indicated continued decomposition of goat manure in the soil, bacteria and microbes absorb its nutrients releasing their products regarded as humus, often attaching to the soil particles.

Organic amendments like goat manure may not always enhance soil moisture retention as effectively as mulching or other physical soil management practices

(Hassan *et al*., 2019). Liana *et al*. (2019) indicated that while manure improves soil organic matter and structure over the long term, its immediate impact on soil moisture can be limited, especially if the manure decomposes rapidly and increases microbial activity that consumes soil moisture. In such cases, the initial benefits of improved soil structure may be offset by increased microbial respiration, leading to a temporary decrease in available moisture.

Organic manure application can sometimes lead to increased soil porosity that favours rapid water drainage, particularly in sandy or well-drained soils, thereby reducing water retention capacity in the short term (Rahman *et al*., 2020). This contrasts with the idea that organic matter uniformly improves water retention, highlighting that the effect is highly context-dependent. In summary, although organic manures like goat manure can improve soil structure and potentially enhance water retention, the immediate or short-term effects are not always positive or consistent across different environments (Hassan *et al*., 2019). Unlike previous studies that shows reduced water retention, my study suggests goat manure and pearl millet mulch contributes to water retention in dryland areas.

4.3 Effects of Goat Manure and Pearl Millet Mulch on Soil Chemical Properties

4.3.1 Soil Chemical Analysis

Soil was analysed at the University of Nairobi, soil laboratory, Upper Kabete Campus whereby the pH ranged between 6.25 and 6.32, total nitrogen 0.15% and 0.41%, organic carbon content 1.05% and 2.13%, K 0.94 and 1.23 Cmol kg^{-1}, P 9.0 mg/L and 13, Mg 0.65 Cmol kg^{-1} and 1.2 Cmol kg^{-1}, Ca 2.10 Cmol kg^{-1} and 3.2 Cmol kg^{-1}, Cu 2.25 mg/L and 2.31 mg/L, Fe 75.2 mg/L and 76.6 mg/L, Mn 94.4 mg/L and 96.2 mg/L, Zn 2.65 mg/L and 3.3 mg/L for trial I and II respectively (Table 3).

Table 3: Soil Analysis Results Prior to Cowpeas Sowing at Tharaka University Demonstration Farm

Soil chemical property	Units	Trial I Value	Ratings	Trial II Value	Ratings
pH (H_2O)	_	6.32	Slightly acidic	6.25	Slightly acidic
N	%	0.15	Low	0.41	Medium
C	%	1.05	Moderate	2.13	Adequate
K	Cmol kg^{-1}	0.94	Sufficient	1.23	Rich
P	Ppm	9.0	Deficient	13	Deficient
Mg	$Cmolkg^{-1}$	0.65	Deficient	1.2	Sufficient
Ca	$Cmolkg^{-1}$	2.10	Sufficient	3.2	Sufficient
Cu	Ppm	2.25	Sufficient	2.31	Sufficient
Fe	Ppm	75.2	Sufficient	76.6	Sufficient
Mn	Ppm	94.4	Rich	96.2	Rich
Zn	Ppm	2.65	Deficient	3.3	Deficient

Source: (University of Nairobi soil laboratory Kabete Campus, 2023/2024)

The pH values of both Trial I and II, respectively, suggest slightly acidic soils, which are generally favorable for most crops. The marginal increase in pH in Trial II could influence nutrient availability, potentially enhancing plant uptake. The nitrogen content increased from 0.15% in Trial I to 0.41% in Trial II, indicating a significant improvement in soil nitrogen status. This enhancement could be attributed to decomposition of organic matter or fertilization practices, which are crucial for crop growth and yield. Organic carbon content nearly doubled from 1.05% to 2.13%, reflecting increased organic matter in the soil. Elevated organic carbon generally improves soil structure, moisture retention, and nutrient cycling, benefiting plant development.

4.3.2 Goat Manure Chemical Analysis

Goat manure was analysed at the University of Nairobi, soil laboratory, Upper Kabete Campus. The pH was 7.44, total nitrogen 0.92%, organic carbon content 6.18 %, K 3.85 Cmol kg^{-1}, P 164.5 ppm, Mg 7.20 Cmol kg^{-1}, Ca 5.23 Cmol kg^{-1}, Cu 0.95 mg/L, Fe 80.8 ppm, Mn 189 mg/L and Zn 9.65 mg/L (Table 4). Goat manure exhibited a neutral pH of 7.44 indicating suitability for agricultural application without causing soil acidity or alkalinity issues. The total nitrogen content of 0.92% suggests that it supplies a moderate amount of nitrogen, essential for plant growth and development. The organic carbon content of 6.18% reflects a good level of organic matter, which can improve soil structure, water retention, and microbial activity.

Table 4: Chemical Analysis of Goat Manure

Type of manure	Chemical property	Units	Value	Ratings
Goat manure	pH (H_2O)	_	7.44	Slightly alkaline
	N	%	0.92	High
	C	%	6.18	Rich
	K	Cmol kg^{-1}	3.85	Rich
	P	Ppm	164.5	Rich
	Mg	Cmolkg^{-1}	7.20	Rich
	Ca	Cmolkg^{-1}	5.23	Sufficient
	Cu	Ppm	0.95	Deficient
	Fe	Ppm	80.8	Sufficient
	Mn	Ppm	189	Rich
	Zn	Ppm	9.65	Sufficient

The potassium (K) level of 3.85 Cmol kg-1 and phosphorus (P) at 164.5 ppm indicate that the manure can contribute significantly to the soil's nutrient pool, supporting overall plant nutrition. Magnesium (Mg) and calcium (Ca) levels 7.20 and 5.23 Cmol kg-1 respectively, are also important for plant physiological functions such as photosynthesis and cell wall stability. Micronutrients like copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) are present in adequate amounts, ensuring that essential trace elements necessary for various enzymatic processes are available for crops.

The findings of this study are consistent with previous research on manure nutrient profiles and their suitability for agricultural use. Dutta *et al*. (2021) found that goat manure typically exhibits a neutral pH (7.0–7.5) and nitrogen contents range 0.8–1.0%, aligning with the current study's pH and nitrogen levels. Their research also emphasized its capacity to improve soil organic matter and nutrient availability.

Studies conducted by Rana and Roy (2024) conducted an analysis of goat manure and found that it contains approximately 0.9% total nitrogen, along with a high organic carbon content of around 6%. This composition is significant because it highlights the manure's dual role as both a source of essential nutrients and an organic matter enhancer for soils. Hutchinson *et al*. (2016) highlighted that goat manure enhances soil organic matter and provides a balanced supply of macro- and micronutrients, consistent with the high P and micronutrient levels observed in this analysis.

The potassium level of 3.85 Cmolkg-1 and high phosphorus concentration of 164.5 ppm are indicative of the manure's capacity to supply essential nutrients necessary for plant growth. Additionally, the micronutrients copper (0.95 mg/L), iron (80.8 ppm), manganese (189 mg/L), and zinc (9.65 mg/L) were present at levels conducive to supporting healthy crop development, further confirming the nutrient-rich profile of goat manure. Studies have reported lower nutrient contents and less favorable characteristics in goat manure, which may limit its effectiveness as a fertilizer. Maluki (2023) indicated that goat manure often has a lower total nitrogen content, averaging around 0.5%, which could reduce its contribution to crop nitrogen needs compared to the 0.92% observed in this study.

According to study conducted by Mandal *et al*. (2019) noted that the pH of goat manure can be more acidic, ranging between 6.0 and 6.5 potentially leading to soil acidification if applied excessively. Organic carbon levels in goat manure have also been reported as lower in certain contexts, around 4.0–5.0%, which might affect its capacity to improve soil organic matter (Ndung'u, 2023). Furthermore, while the phosphorus concentration was high in this analysis (164.5 mg/L), other studies have documented much lower P levels, ranging about 80–100 mg/L, which could limit its role in promoting robust plant growth (Djouego *et al*., 2024). Micronutrient levels such as Fe and Mn have also been found to be variable, sometimes below optimal ranges for crop nutrition (Menge *et al*., 2024). These discrepancies suggest that the nutrient profile and effectiveness of goat manure can vary widely depending on factors such as diet, manure age, and environmental conditions, highlighting the need for site-specific assessments before application.

4.3.3 Soil Chemical Properties of Pearl Millet Mulch and Goat Manure in Trial I and II Treatments

The application of goat manure and pearl millet stubble mulch significantly ($p < 0.05$) improved soil fertility parameters, including nitrogen (N), and organic carbon (C), compared to the control treatment across the different cowpea varieties in both Trials I and Trial II (Table 5). Nitrogen (N) and organic carbon (C) increased in the following order from: control; mulch; goat manure, indicating that the treatments progressively enhanced soil fertility. These results demonstrate that both goat manure and pearl millet mulch significantly ($p < 0.05$) enhanced soil nutrient contents compared to the control, with goat manure generally contributing higher nutrient levels in N and Carbon (Appendix 7).

In trial I goat manure had; Nitrogen (N): 0.69%, Organic Carbon (C): 1.33%, Potassium (K): 1.41 Cmol kg^{-1}, Phosphorus (P): 12.48 ppm, Pearl millet mulch showed nutrient levels of: N: 0.16%, C: 1.21%, K: 1.94 $Cmolkg^{-1}$, P: 16.67 ppm. Control recorded; Nitrogen (N): 0.15%, Organic Carbon (C): 1.2%, Potassium (K): 1.41 Cmol kg^{-1}, Phosphorus (P): 12.37 ppm (Table 5). In Trial 2, goat manure recorded the highest nutrient contents with: N: 0.28%, C: 2.8%, K: 1.28 $Cmolkg^{-1}$, P: 142.6 ppm, Pearl millet mulch showed nutrient levels of: N: 0.17%, C: 1.36%, K: 1.17 $Cmolkg^{-1}$, P: 154.4 ppm. The control treatment under the same variety recorded: Nitrogen (N): 0.12%, Organic Carbon (C): 0.88%, Potassium (K): 1.06 Cmol kg^{-1}, Phosphorus (P): 121.6 ppm (Table 5).

The observed trends indicate that both goat manure and pearl millet stubble mulch significantly enhance soil fertility parameters compared to the control, with goat manure showing the most pronounced effect. The progressive increase in nitrogen, phosphorus, potassium, and organic carbon from control to mulch to manure suggests that these treatments improve soil conditions by adding organic matter and nutrients essential for crop growth. The high organic carbon content in goat manure is likely attributed to their diet, which consists of carbon-rich fibrous materials containing cellulose and lignin that are later excreted as manure. Similarly, the high nitrogen content results from goats feeding on grasses and legumes rich in proteins composed of amino acids, which contain nitrogen. Additionally, goats excrete nitrogen in the form of urea, further increasing the nitrogen content in their feces.

Table 5: Effects of Goat Manure and Pearl Millet Mulch on Soil Macronutrients in Trial I and II under Cowpeas

Trial	Cowpea Variety	Treatment	pH (H_2O)	N (N%)	C (%)	K (Cmol kg^{-1})	P (ppm)
I	K80	CONT	6.56^{a}	0.12^{a}	1.18^{ab}	1.18^{ab}	12.37^{a}
		GM	6.82^{abc}	0.69^{c}	1.28^{cd}	1.39^{ab}	12.48^{a}
		PMM	6.72^{ab}	0.15^{a}	1.21^{bcd}	1.65^{ab}	12.10^{a}
	KVU 27-1	CONT	6.63^{a}	0.15^{a}	1.18^{abcd}	1.26^{ab}	11.67^{a}
		GM	6.46^{a}	0.26^{ab}	1.18^{abcd}	1.14^{ab}	12.47^{a}
		PMM	6.43^{a}	0.16^{ab}	0.99^{abcd}	1.37^{ab}	16.67^{a}
	M66	CONT	6.75^{ab}	0.14^{a}	1.19^{abcd}	1.41^{ab}	9.53^{a}
		GM	6.83^{abcd}	0.49^{bc}	1.33^{cd}	1.41^{ab}	12.47^{a}
		PMM	6.71^{ab}	0.14^{a}	1.06^{abcd}	1.94^{b}	12.67^{a}
II	K80	CONT	7.36^{e}	0.07^{a}	0.77^{ab}	1.06^{a}	121.60^{de}
		GM	7.42^{e}	0.19^{ab}	2.21^{e}	1.24^{ab}	92.63^{bcd}
		PMM	7.41^{e}	0.17^{ab}	1.36^{d}	1.17^{ab}	98.33^{bcde}
	KVU27-1	CONT	7.34^{de}	0.12^{a}	0.74^{a}	1.05^{a}	54.96^{ab}
		GM	7.46^{e}	0.28^{ab}	2.80^{f}	1.28^{ab}	142.60^{de}
		PMM	7.21^{bcde}	0.15^{a}	1.09^{abcd}	1.11^{ab}	154.43^{e}
	M66	CONT	7.29^{cde}	0.12^{a}	0.88^{abc}	1.06^{ab}	119.60^{de}
		GM	7.50^{e}	0.16^{ab}	1.40^{d}	1.24^{ab}	116.30^{cde}
		PMM	7.52^{e}	0.14^{a}	1.20^{bcd}	1.06^{a}	60.20^{abc}
		Mean	7.023	0.206	1.282	1.277	59.6
		CV (%)	2.3	50.5	11.0	21.2	30.4
		$LSD_{(0.05)}$	0.2625	0.1724	0.2340	0.4498	30.2
		P-Value	0.167	0.001	0.001	0.073	0.273

Legend: CONT-control, GM-Goat Manure, PMM-Pearl Millet Mulch. Means with the same letters within the column are not significantly different (P <0.05).

Specifically, goat manure consistently resulted in higher nutrient levels, likely due to its rich organic content and nutrient density, which promote better soil health. In Trial 2 under the M66 variety, goat manure led to the highest nutrient concentrations such as nitrogen at 0.28%, organic carbon at 2.8%, potassium at 1.28 Cmolkg-1, and phosphorus at 142.6 ppm highlighting its superior capacity to boost soil fertility. Pearl millet stubble mulch also improved nutrient levels over the control but to a lesser extent, reflecting its role as a beneficial organic residue that gradually enhances soil nutrients. M66 seems to produce higher number of root exudates and fine roots. The exudates stimulate microbial activities resulting to organic carbon through decomposition and mineralization. Also, M66 might be having higher cation exchange cations of potassium as compared to KVU 27-1 and K80.

The findings align with previous studies of Celestina *et al*. (2019) who conducted a comprehensive study on the impact of organic amendments such as manure and crop residues on soil health and fertility. Their research demonstrated that applying organic materials to the soil substantially enhances nutrient availability by increasing the levels of essential nutrients like nitrogen, phosphorus, and potassium. These nutrients are crucial for plant growth and development, and their increased presence in the soil translates into improved crop yields and overall productivity. The improvements are often associated with increased plant growth and yield, as observed in the current trials. Similarly, Dutta *et al*. (2021) found that organic amendments such as manure and crop residues enhance soil fertility indicators, including pH, nitrogen, and organic carbon, leading to improved crop yields. Their findings corroborate the observed trend where organic amendments elevate soil nutrient levels.

Findings by Michael (2021) reported that excessive or improper application of organic manure could potentially lead to nutrient imbalances or soil acidification over time, which could counteract the benefits. Additionally, certain research suggests that the effectiveness of organic amendments may vary depending on soil type, crop variety, and environmental conditions, indicating that the positive effects observed in this study might not be universally applicable (Wei *et al*., 2016). The current findings support the beneficial impact of goat manure and pearl millet stubble mulch on soil fertility. Overall, the findings confirm that goat manure and pearl millet stubble mulch as organic amendments are effective strategies for improving soil fertility in cowpea cultivation, with goat manure showing a more pronounced effect across most parameters.

The application of goat manure and pearl millet mulch significantly improved soil fertility ($p < 0.05$) by increasing levels of Mg and Ca compared to the control in trial II (Appendix 7). Across the three M66, K80 and KVU 27-1 cowpea varieties soil nutrient levels followed an increasing the trend from: control; pearl millet mulch; goat manure (Table 6). The trends clearly show that applying goat manure and pearl millet mulch significantly enhances soil micronutrient levels compared to the control, with goat manure producing the most substantial increases.

In Trial I, goat manure recorded Mg (1.42 Cmol kg^{-1}), Ca (2.50 Cmol kg^{-1}), Cu (1.64 ppm), Fe (90.9 ppm), Mn (127.6 ppm), and Zn (3.91 ppm); pearl millet mulch showed Mg (0,76 Cmol kg^{-1}), Ca (2.14 Cmol kg^{-1}), Cu (1.66 ppm), Fe (76.6 ppm), Mn (122.1 ppm), and Zn (3.67 ppm); the control had Mg (0.92 Cmol kg^{-1}), Ca (2.33 Cmol kg^{-1}), Cu (1.87ppm), Fe (94.2ppm), Mn (140.7 ppm), and Zn (3.81 ppm) (Table 6).

In Trial II, goat manure recorded Mg (4.09 Cmol kg^{-1}), Ca (6.70 Cmol kg^{-1}), Cu (1.51 ppm), Fe (158.2 ppm), Mn (134.6 ppm), and Zn (3.073 ppm); pearl millet mulch showed Mg (3.94 Cmol kg^{-1}), Ca (5.58 Cmol kg^{-1}), Cu (1.81 ppm), Fe (142.5 ppm), Mn (122 ppm), and Zn (3.0 ppm); the control had Mg (3.45 Cmol kg^{-1}), Ca (4.90 Cmol kg^{-1}), Cu (1.6ppm), Fe (144.3 ppm), Mn (94.5 ppm), and Zn (3.15 ppm) (Table 6).

In the study goat manure and pearl millet mulch enhanced soil fertility by increasing essential micronutrients and macronutrients. Studies by Sunaryo *et al*., (2018) reported that organic manure significantly elevates soil levels of Mg, Ca, and micronutrients, which supports crop growth. Dhaliwal *et al*. (2022) observed that the application of manure has a profound positive impact on soil nutrient content, particularly enhancing the levels of micronutrients such as iron (Fe), manganese (Mn), and zinc (Zn). These micronutrients are essential for various physiological and biochemical processes in plants, including chlorophyll synthesis, enzyme activation, and overall metabolic functions. Their availability in the soil directly influences plant health, growth, and development. This was the first study to investigate the effects of goat manure and pearl millet mulch on improvement of macronutrients and micronutrients in arid and semi-arid lands.

Table 6: Effects Goat Manure and Pearl Millet Mulch on Soil Micro-nutrients in Trial I and II under Cowpeas

Trial	Cowpea Variety	Treatment	Mg (Cmolkg^{-1})	Ca (Cmolkg^{-1})	Cu (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)
I	K80	CONT	0.92^{a}	2.31^{ab}	1.13^{abc}	77.6^{a}	119.4^{abc}	3.73^{bcd}
		GM	0.42^{a}	2.50^{b}	1.62^{c}	90.7^{abc}	127.6^{abc}	3.91^{d}
		PMM	0.73^{a}	1.60^{ab}	1.32^{abc}	76.6^{a}	122.1^{abc}	3.27^{abcd}
	KVU27-1	CONT	0.92^{a}	2.33^{ab}	1.31^{abc}	81.0^{a}	131.1^{abc}	3.81^{cd}
		GM	0.66^{a}	2.31^{ab}	1.53^{bc}	85.5^{ab}	120.0^{abc}	3.74^{bcd}
		PMM	0.76^{a}	2.14^{ab}	1.66^{c}	75.6^{a}	98.3^{ab}	3.67^{bcd}
	M66	CONT	0.80^{a}	2.23^{ab}	1.87^{c}	94.2^{abcd}	140.7^{c}	3.54^{abcd}
		GM	1.42^{a}	2.48^{b}	1.64^{c}	90.9^{abc}	125.4^{abc}	3.91^{d}
		PMM	0.74^{a}	1.09^{a}	1.32^{abc}	74.1^{a}	120.8^{abc}	3.07^{abcd}
II	K80	CONT	3.42^{b}	4.90^{cd}	1.60^{c}	144.3^{e}	90.4^{a}	2.84^{abc}
		GM	4.01^{b}	5.82^{de}	1.17^{abc}	146.5^{e}	134.6^{bc}	3.07^{abcd}
		PMM	3.94^{b}	5.20^{cd}	1.81^{c}	139.2^{e}	122.0^{abc}	3.00^{abcd}
	KVU27-1	CONT	3.45^{b}	4.60^{cd}	0.80^{ab}	122.3^{bcde}	94.5^{ab}	3.15^{abcd}
		GM	4.09^{b}	6.70^{e}	1.51^{bc}	129.5^{cde}	112.9^{abc}	2.62^{a}
		PMM	3.50^{b}	5.58^{cde}	1.21^{abc}	131.3^{de}	98.1^{ab}	2.81^{abc}
	M66	CONT	3.40^{b}	4.44^{c}	1.27^{abc}	126.4^{cde}	90.9^{a}	2.88^{abc}
		GM	4.06^{b}	4.91^{cd}	0.65^{a}	158.2^{e}	123.0^{abc}	3.19^{abcd}
		PMM	3.42^{b}	4.79^{cd}	1.13^{abc}	142.5^{e}	95.5^{ab}	2.76^{ab}
		Mean	2.315	3.661	1.365	110.4	114.8	3.277
		CV (%)	13.8	10.5	17.61	11.1	11.1	9.5
		$LSD_{(0.05)}$	0.5295	0.6353	0.3978	20.32	21.06	0.5160
		P-Value	0.001	0.001	0.606	0.031	0.003	0.014

Legend: CONT-control, GM-Goat Manure, PMM-Pearl Millet Mulch. Means with the same letters within the column are not significantly different ($P < 0.05$).

The extent of nutrient increase depends on the initial soil conditions and the type of organic material used. Lorenz and Lal (2023) stated that organic amendments generally improve soil nutrient status, but the magnitude can vary based on application rates and climate factors. In study, the observed increases in soil nutrients with goat manure and pearl millet mulch are consistent with the literature emphasizing organic matter's role in enhancing soil fertility (Gerke, 2022). There are notable contradictions to the findings suggesting that goat manure and pearl millet mulch consistently increase soil nutrients, some studies have reported limited or negligible effects on soil fertility, particularly in the short term. Das *et al.* (2023) found that the application of goat manure did not significantly improve soil nitrogen and phosphorus levels within a single growing season, attributing this to rapid mineralization or nutrient leaching.

Studies by Ibrahim *et al*. (2018) indicated that organic amendments like pearl millet mulch may temporarily suppress microbial activity or impede nutrient release, thereby limiting immediate nutrient availability. Other studies have pointed out that the nutrient boost from goat manure can be inconsistent due to variability in manure quality, application methods, and environmental conditions, which may result in minimal or delayed improvements in soil fertility (Washaya & Washaya, 2023). The research findings highlight that the positive impacts of organic amendments such as goat manure and pearl millet mulch are not always guaranteed and may depend heavily on management practices and site-specific factors but variations in nutrient levels across studies highlight the influence of contextual factors.

4.4 Effects of Goat Manure and Pearl Millet Mulch on Growth and Yield of Selected Cowpea Varieties

4.4.1 Plant Height and Stem Girth of Cowpea

Plant height and stem girth were high in in trial II than in trial I with significant increase in plant height and stem girth with increase in number of days. In both trials, plant height and stem girth across treatments and days were significant ($p < 0.05$) (Table 7).

Table 7: Effects of Goat Manure and Pearl Millet Stubble on Plant Height and Stem Girth of Cowpea

Trial	Cowpea Variety	Treatment	PHT14DAS	PHT28DAS	PHT42DAS	PHT56DAS	SG14DAS	SG28DAS	SG42DAS	SG56DAS
I	K80	CONT	5.55^{a}	9.34^{ab}	12.06^{a}	13.83^{a}	0.85^{a}	1.31^{a}	1.81^{a}	1.87^{a}
		GM	6.27^{bc}	12.33^{abcd}	13.32^{ab}	18.26^{ef}	1.19^{abcd}	2.30^{d}	2.22^{ab}	2.98^{ab}
		PMM	10.75^{d}	13.27^{bcd}	17.18^{def}	18.53^{ef}	1.16^{abcd}	1.66^{ab}	2.01^{ab}	2.27^{b}
	KVU 27-1	CONT	5.80^{a}	9.40^{ab}	13.22^{ab}	15.38^{abc}	0.84^{a}	1.33^{a}	2.00^{ab}	2.29^{b}
		GM	6.74^{ab}	11.27^{abc}	14.20^{abcd}	18.93^{ef}	1.22^{d}	2.23^{d}	2.66^{abc}	2.80^{ab}
		PMM	10.94^{de}	16.24^{ef}	20.63gh	23.29ghf	1.08^{abc}	1.66^{ab}	2.24^{ab}	2.53^{ab}
	M66	CONT	7.16^{bc}	11.53^{abc}	13.71^{abc}	16.05^{abcd}	0.92^{ab}	1.84^{abcd}	2.40^{ab}	2.52^{ab}
		GM	7.59^{bc}	14.20^{de}	16.39^{de}	21.59^{g}	1.23^{d}	2.86^{f}	4.29^{e}	4.35^{abcd}
		PMM	11.51^{e}	21.28^{g}	30.58^{f}	35.38^{f}	1.14^{abcd}	2.57^{e}	3.1^{abcd3}	3.38^{abc}
II	K80	CONT	5.59^{a}	7.35^{a}	13.17^{ab}	14.76^{ab}	0.85^{a}	1.32^{a}	1.81a	1.93^{a}
		GM	8.21^{c}	12.33^{abcd}	13.47^{ab}	19.46^{def}	1.19^{abcd}	2.37^{d}	2.27^{ab}	2.95^{ab}
		PMM	9.47^{d}	14.02^{de}	18.26^{g}	19.29^{def}	1.67^{e}	1.72^{abc}	2.02^{ab}	2.26^{b}
	KVU 27-1	CONT	6.30^{bc}	8.15^{a}	12.59^{a}	17.54^{cdef}	0.84^{a}	1.35^{a}	2.00^{ab}	2.26^{b}
		GM	6.93^{bc}	12.21^{abcd}	14.61^{abcd}	19.53^{def}	1.23^{d}	2.28^{d}	2.66^{abc}	2.87^{ab}
		PMM	10.04^{d}	17.01^{efg}	21.03gh	24.43^{ghf}	1.09^{abc}	1.70^{abc}	2.24^{ab}	2.54^{b}
	M66	CONT	7.13^{bc}	12.52^{abcd}	14.09^{abcd}	17.39^{cdef}	0.92^{ab}	1.80^{abcd}	2.36^{ab}	2.48^{b}
		GM	8.30^{c}	15.41^{def}	16.55^{de}	22.52^{gh}	1.28^{d}	2.83^{f}	4.25^{e}	4.38^{abcd}
		PMM	11.49^{e}	22.03^{g}	31.25^{f}	37.46^{f}	1.16^{abcd}	2.56^{e}	3.14^{abcd}	3.39^{abc}
		Mean	8.0977	13.326	17.017	20.756	1.0755	1.9806	2.5227	2.779
		CV (%)	1.4	4.7	5.5	7.0	5.9	6.0	2.7	6.7
		LSD$_{(0.05)}$	0.18079	1.0126	1.4984	2.3339	0.10255	0.19114	0.10877	0.2985
		P- Value	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Legend: CONT-control, CV (%) - Coefficient of variation, LSD-Least significance difference, GM-Goat Manure, PMM-Pearl Millet Mulch, PHT-Plant Height, SG-Stem Girth and DAS-Days after Sowing. Means with the same letters within the same column are not significantly different (P <0.05).

The application of goat manure and pearl millet stubble mulch showed significant ($p < 0.05$) different effect on plant height and stem girth compared to control treatments (Appendix 8 and Appendix 9). Similar trends were observed across all cowpea varieties in both trials. The variety M66 having higher plant height of 35.38 cm, 37.46 cm at 56 DAS in trial I and II respectively, under PMM (Table 7). The M66 variety had also higher stem girth of 4.35 cm, and 4.38 cm under GM at 56 DAS in trial I and II respectively (Table 7). In Trial I, plant height measured at 14, 28, 42, and 56 days after sowing (DAS) was highest under pearl millet mulch, recording 11.51, 21.28, 30.58, and 35.38 cm, respectively, followed by goat manure with 7.59, 14.20, 16.39, and 21.59 cm, and the control with 7.16, 11.53, 13.71, and 16.05 cm in M66 variety (Table 7). In trial II plant height was highest at PMM with 11.49, 22.03, 31.25 and 37.46 followed by goat manure with 8.30, 15.41, 16.55 and 22.52 cm and control with 7.13, 12.52,14.09 cm and 17.54 cm at 14, 28, 42 and 56 DAS. Stem girth highest with goat manure 1.23, 2.86, 4.29 cm, and 4.35 cm, followed by pearl millet mulch 1.16, 2.57, 3.1, 3.38 and the control 0.92, 1.84, 2.40, 2.52 cm in trial one (Table 7). Trial II under goat manure stem girth was 1.28, 2.83, 4.25 and 4.38 cm, pearl millet was 1.67, 2.56, 3.14 and 3.39 cm while in control 0.92, 1.80, 2.36 and 2.48 cm (Table 7). The plant height increased in different treatments in the following order from; control; goat manure; pearl millet stubble mulch in three cowpea varieties in both trials.

The stem girth increased in different treatment in the following order control: pearl millet mulch; goat manure in three cowpeas varieties. The highest stem girth was observed at M66 (4.25 cm) followed by K80 and KVU 27-1 at 56 DAS and lowest (0.84 cm) on KVU 27-1 variety at 14 DAS (Table 7). This indicated an increasing trend of plant height and stem girth of cowpeas plants with increase in the numbers of days after sowing in trial I and II. The plant height and stem girth of cowpea plants increased with increasing number of days after sowing with the application of goat manure and pearl millet stubble mulch.

M66 cowpea variety, genetically has high vegetative vigour. It is a variety that allows apical dominance allowing vertical growth prior to branching as compared to KVU 27-1 and K80 with earlier branching reducing assimilates to lateral branches instead of increased size of stem. M66 variety have leaves with larger area with high content of chlorophyll increasing chances of high photosynthetic rates, hence more assimilates attributed to rapid cell division resulting to faster secondary growth ultimately increased stem height and girth as compared to KVU 27-1 and K80.

The results indicate that the use of pearl millet stubble mulch positively influenced the growth of cowpea plants, by improving soil conditions such as moisture retention, nutrient availability, and soil temperature regulation. These favorable soil conditions promoted more vigorous plant growth, leading to taller cowpea plants as observed in the measurements across different sampling times. This trend suggests that pearl millet stubble mulch can be an effective organic mulching practice to enhance cowpea growth performance.

The findings corroborate with those of Fatondji *et al*. (2024) who reported that pearl millet stubble mulch contributed to improved cowpea growth, primarily by enhancing key soil properties such as moisture conservation, nutrient supply, and temperature moderation. Pearl millet stubble mulch provide a physical contact with surface of the soil obstructing runoff movement, reducing speed, providing longer time for rainwater infiltration (Sharma, 2018). The capacity to improve water infiltration in the soil and microbial activities serves as essentials in promoting nutrients flow, consequently better plant growth in terms to plant height and stem girth.

The findings of this study agree with those of Fetri *et al*. (2015) who reported that organic mulch application increased the height of chickpea. The plant height and stem girth increased due to the physical contact of organic mulch with the soil surface, reducing the surface runoff and increasing infiltration as well as improving microbial activities of the soil responsible for increased plant height (Biswas *et al*., 2022). Organic mulch efficiently reduces nitrate leaching, consequently providing nitrate ions for synthesising amino acids making proteins and enzymes aiding metabolic processes, promoting plant growth due to secondary growth(Xiukang *et al*., 2015). Also, organic mulch reflects solar radiation stabilising the soil temperatures, reducing evaporation rate while increasing the water holding capacity of the soil (El-Beltagi *et al*., 2022).

The analysed goat manure showed high amount of major nutrients (organic carbon content, total nitrogen, potassium, and phosphorus) and minor nutrients (manganese, magnesium, zinc and copper). The nutrients were possibly responsible for improved soil fertility promoting plant height and stem girth. The nutrients help the crop in building proteins, hormones, vitamins, activation of enzymes, hence increased cell division (Xiukang *et al*., 2015). Goat manure application act as soil fertility management strategy improving soil physical conditions allowing water infiltration and retention (Kumar *et al*., 2022). Progressive decomposition of goat manure in the soil, bacteria and microbes absorb its nutrients releasing humus attaching to soil particles (Kassam & Mkomwa, 2022). Therefore, the humus separate the dense particles of clay soil enhancing drainage with large particles being filled with water. The increasing trend in plant height and stem girth was attributed to improved physical, biological and chemical properties of soil.

The goat manure application increasing trend in cowpea plant height aligns with the study of Singh *et al*. (2020) those organic fertilizers like goat manure supply essential nutrients such as nitrogen, phosphorus, and potassium, thereby promoting vigorous plant growth and development. The high nutrient content identified in the goat manure, including organic carbon, total nitrogen, and trace minerals, supports these findings, as these components are critical for plant health and biomass accumulation.

Study conducted by Michael (2021) reported excessive application of organic manure can sometimes lead to nutrient imbalances or delayed nutrient release, potentially causing uneven growth or soil nutrient buildup, which may negatively impact plant health. Additionally, in certain soil types with poor drainage or low pH, organic manure might contribute to soil acidification or waterlogging if not properly managed (Babu *et al*., 2020). Therefore, while the positive effects of goat manure on cowpea growth are well-documented, they depend heavily on proper application rates and soil conditions to avoid potential adverse effects.

4.4.2 Number of Leaves, Leaf Area, Leaf Area Index and Branches of Cowpea

The number of leaves, leaf area, and number of branches in trial I and II treatment means were significantly different ($p < 0.05$) at different days of growth under goat manure and pearl millet stubble mulch (Appendix 10, 11 and 13). Number of leaves, leaf area, and number of branches increased from; control; pearl millet stubble mulch and goat manure in the three cowpea varieties in trial I and II **(**Table 8**)**. The variety M66 had highest number of leaves 41.33 and 42.58 under goat manure at 42 DAS in both trial I and II, respectively. Leaf area was 40.88 and 40.20 at 49 DAS in trial I and

II under goat manure for M66 variety. At 42 DAS number of branches were 7.25 and 7.75 in trial I and II, respectively under goat manure. The number of leaves under goat manure was; 3.83, 12.67, 41.33 and 28.00, in pearl millet mulch 3.00, 12.33, 38.58 and 32.83 and control had 2.17, 8.42, 23.92 and 23.75 at 14, 28, 42 and 56 DAS in trial 1, respectively (Table 8).

Table 8: Effects of Goat Manure and Pearl Millet Mulch on Number of Leaves, Leaf Area, Leaf Area Index and Branches of Cowpea

Trial	Cowpea variety	Treatment	NOL14 DAS	NOL28 DAS	NOL42 DAS	NOL56 DAS	LA49 DAS	LAI49 DAS	NOB28 DAS	NOB42 DAS	NOB56 DAS
I	K80	CONT	2.17^{a}	7.17^{ab}	21.25^{b}	18.33^{c}	12.52^{a}	0.11^{b}	2.25^{a}	3.83^{b}	3.67^{a}
		GM	3.83^{abcd}	12.42^{efgh}	34.08^{de}	27.92^{def}	22.43^{cd}	0.12^{c}	3.75^{c}	5.25^{cd}	6.33^{cd}
		PMM	3.00^{ab}	12.33^{efgh}	31.17^{d}	29.67^{ef}	17.68^{b}	0.11^{b}	3.67^{c}	5.25^{cd}	6.25^{cd}
	KVU 27-1	CONT	2.00^{a}	6.50^{a}	15.17^{a}	12.75^{a}	17.71^{b}	0.13^{e}	2.17^{a}	3.42^{a}	3.67^{a}
		GM	3.17^{ab}	10.92^{cdef}	28.25^{cd}	22.00^{d}	27.17^{de}	0.11^{b}	3.75^{c}	5.25^{cd}	5.83^{c}
		PMM	3.00^{ab}	7.58^{abc}	25.42^{cd}	24.08^{de}	17.62^{b}	0.13^{d}	4.17^{cde}	4.42^{c}	5.50^{c}
	M66	CONT	2.17^{a}	8.42^{abcde}	23.92^{c}	23.75^{de}	21.63^{cd}	0.09^{a}	3.00^{b}	3.92^{b}	4.25^{b}
		GM	3.83^{abcd}	12.67^{gh}	41.33^{ef}	28.50^{def}	40.88^{efg}	0.10^{b}	4.25^{cdef}	7.25^{cde}	7.08^{cde}
		PMM	3.00^{ab}	11.08^{defg}	38.58^{e}	32.83^{efg}	32.91^{def}	0.10^{b}	3.75^{c}	5.42^{cd}	6.58^{cd}
II	K80	CONT	2.00^{a}	7.17^{ab}	21.08^{b}	17.17^{b}	13.22^{a}	0.12^{c}	2.25^{a}	3.92^{b}	3.75^{a}
		GM	3.75^{abc}	12.50^{efgh}	34.25^{de}	24.67^{de}	24.31^{d}	0.13^{d}	3.75^{c}	5.67^{cd}	6.42^{cd}
		PMM	3.00^{ab}	12.58^{gh}	31.17^{d}	27.67^{def}	17.68^{b}	0.11^{b}	3.67^{c}	5.50^{cd}	6.33^{cd}
	KVU 27-1	CONT	2.00^{a}	6.75^{a}	15.08^{a}	13.33^{a}	18.14^{c}	0.13^{d}	2.17^{a}	3.50^{a}	3.83^{a}
		GM	3.67^{abc}	11.33^{defg}	38.25^{e}	21.00^{d}	26.74^{de}	0.10^{b}	3.92^{cd}	5.42^{cd}	5.92^{c}
		PMM	3.00^{ab}	8.00^{abcd}	25.25^{cd}	23.42^{de}	17.62^{b}	0.13^{d}	4.08^{cde}	4.58^{c}	5.75^{c}
	M66	CONT	2.17^{a}	8.75^{abcde}	23.75^{c}	16.25^{b}	21.36^{cd}	0.11^{b}	3.00^{b}	4.08^{c}	4.33^{b}
		GM	3.92^{bcde}	13.08^{ghi}	42.58^{efg}	28.00^{def}	40.20^{efg}	0.10^{b}	4.33^{cdef}	7.75^{cde}	7.17^{cde}
		PMM	3.00^{ab}	11.25^{defg}	38.42^{e}	33.83^{efg}	31.88^{def}	0.11^{c}	3.92^{cd}	5.83^{cd}	6.92^{cd}
		Mean	2.926	10.028	28.833	23.620	23.42	0.113	3.435	5.014	5.532
		CV (%)	10.9	6.1	2.9	4.7	7.3	13.6	11.2	10.0	10.7
		$LSD_{(0.05)}$	0.5126	0.9874	1.3350	1.7818	2.743	0.0248	0.6230	0.8089	0.9598
		P-Value	0.001	0.001	0.001	0.001	0.001	0.016	0.001	0.001	0.001

Legend: CONT-control, CV (%) - Coefficient of variation, LSD-Least significance difference, GM-Goat Manure, PMM-Pearl Millet Mulch, DAS-Days after Sowing, NOL-Number of Leaves, LA-Leaf Area, LAI-Leaf Area Index and NOB-Number of Branches. Means with the same letters within the same column are not significantly different ($P < 0.05$).

Number of leaves in trial II under goat manure was recorded as 3.92, 13.08, 42.58 and 28.00, in pearl millet mulch was 3.00, 12.58, 38.42 and 33.83, while control 2.17, 8.75, 23.75 and 16.25 at 14, 28, 42 and DAS respectively. At 49 DAS leaf area was 40.88, 32.91 and 21.63 under goat manure, pearl millet and control respectively in trial I for M66 (Table 8). In trial II leaf area was 40.20, 31.88 and 21.36 under goat manure, pearl millet and control at 49 DAS for K80 and KVU 27-1 under trial II. Leaf area index under goat manure was 0.12 and 0.13 in both trials. Leaf area index under PMM was 0.13 in both trials. Number of branches under goat manure were; 4.25, 7.25 and 7.08 while pearl millet stubble mulch had; 4.17, 5.42 and 6.58 and control 3, 3.92 and 4.25 at 28, 42 and 56 DAS, respectively in trial I (Table 9**).** Trial II the number of branches under goat manure were; 4.33, 7.75 and 7.17, in pearl millet; 4.08, 5.83 and 6.92 and control recorded; 3, 4.08 and 4.33 at 28, 42 and 56 DAS, respectively (Table 8).

In the study there was increasing trend in the number of leaves, leaf area and number of branches in response to application of goat manure and pearl millet stubble mulch in trial I and II. The mean number of leaves, leaf area and number of branches increased in this order; control; pearl millet stubble mulch; goat manure in both trials (Table 8). The trends demonstrate that the application of goat manure and pearl millet stubble mulch significantly promotes plant growth attributes such as leaf number, leaf area, and the number of branches, with the greatest improvements observed with goat manure. Across both trials, these growth parameters increased in the order: control, pearl millet stubble mulch, and goat manure, indicating that organic soil amendments positively influence plant development. Specifically, goat manure and pearl millet mulch enhances the plant's foliage and branching, likely due to improved soil fertility.

Studies by Ibukunoluwa Moyin-Jesu (2015) reported similar positive effects of organic amendments and mulches on vegetative growth parameters, though the magnitude and timing of responses can vary depending on the treatment types and environmental conditions. Ibukunoluwa Moyin-Jesu (2015) observed that application of organic manures such as cow dung and compost led to significant increases in leaf number, leaf area, and branch development in cereal crops, with the most pronounced effects seen at higher application rates. Similarly, Bana *et al*. (2023) reported that pearl millet stubble mulch, when applied at appropriate rates, improved soil moisture retention and nutrient availability, resulting in increased leaf area index and branch number in subsequent crop cycles.

The increase in the number of leaves, leaf area and number of branches witnessed in goat manure could be attributed to the high (92%) total nitrogen content (Table 4). Studies by Leghari *et al*. (2016) stated that presence of nitrogen in the soil stimulates new leaves production arising from the terminal meristem and older leaves lateral buds**.** Enzymes and proteins are made of building amino acids made of nitrogen as a macronutrient. Structurally plants are made of proteins facilitating biochemical reactions.

Chlorophyll is made of nitrogen as a component enabling sunlight energy capture through photosynthesis, providing plants with phosynthates for increased number of leaves, leaf area, leaf area index and number of branches (Fathi, 2022). Additionally, the presence of nitrogen in roots as enzymes and proteins promotes nutrient uptake and water regulation. Another reason for the increased number of leaves and number of branches could be that magnesium and phosphorus were rich from goat manure (Table 4)**.** According to Bhatla and Kathpalia (2023) magnesium serves as core component of chlorophyll, aiding sunlight absorption during photosynthesis, it acts as a carrier of phosphorus and phosphate metabolism in plants in addition to cell division of plants increasing cowpea growth.

The observed anomalies in trend in the increase of the number of leaves despite the application of pearl millet stubble mulch may be attributed to initial nutrient immobilization or microbial competition, which can temporarily suppress plant growth before the organic matter decomposes and releases nutrients (Ibrahim *et al*., 2018). A high C:N ratio organic material tends to favor microbial immobilization of nitrogen, reducing its immediate availability to plants (Pang *et al*., 2022). Consequently, during the initial decomposition phase, plants may experience nutrient deficiency, leading to unexpected or reduced leaf development. It is only after microbial activity stabilizes and organic matter decomposes that nutrients are mineralized and become accessible to the plants, potentially resulting in improved growth parameters at later stages. Although the overall trend of leaf number is expected to increase over time, indicating the effectiveness of pearl millet mulch as an organic amendment, early-stage nutrient uptake limitations can cause a transient reduction in vegetative growth (Mutiso, 2018).

The noted increase in the number of leaves, leaf area, leaf area and number of branches could be due to improved water infiltration, retention, evaporation rate reduction and soil temperature regulation through reduction of solar radiation contributed by application of stubble mulch. Studies by Doba (2016) stated that organic mulch reduces soil temperatures by 0.4-4% due to interception of hot air and solar radiation from entering into the layers of soil. The response of plants is due to higher availability of water that makes plant nutrients available for translocation and maintaining required cell turgidity. According to Adewumi *et al*., (2020) organic mulches reduce raindrop impacts on the soil reducing surface runoff and detaching of soil particles minimising soil erosion ad surface runoff respectively. Hence, the water and soil nutrients are available to the plants increasing its growth rates. Studies by Xiukang *et al*. (2015) have shown crop residues act as soil surface and shade against losses of moisture and vapour barrier improving moisture retention 6-20% and infiltration rate by 10-12%.

Studies by Wang *et al*. (2023) reported that organic mulches undergo slow decomposition, contributing to soil organic carbon, helping in soil structure amelioration. This organic matter improves aggregate stability of the soil. Consequently, the aggregates of macro-waters get stabilized, acting as binding agents that help in soil water retention. Availability of substrate in organic mulches, optimal soil temperatures and moisture retention contribute to conducive environment for decomposers (Demo & Asefa Bogale, 2024). Crop residues respond on decreasing diurnal variations and attenuating the rising soil temperature increasing activities of micro bacteria increasing earthworm density (Wang *et al*., 2023). Such activities of organic manure contribute to more water and nutrients availability to plants, facilitating plant growth.

Research findings by Bhunia *et al*. (2021) observed that high rates of organic manure, including goat manure, sometimes resulted in nutrient imbalances or phytotoxic effects, leading to reduced leaf number and leaf area in some crops. Similarly, Saikanth *et al*. (2023) reported that improper application timing or excessive mulch application could create unfavorable microenvironments, such as reduced oxygen diffusion or increased pest incidence, which negatively impacted plant growth. Additionally, some studies suggest that organic mulches like pearl millet stubble may temporarily inhibit seedling emergence or early growth due to allelopathic compounds or moisture competition (Sharma, 2023).These contrasting findings emphasize that the effectiveness of organic amendments can vary depending on application rates, timing, environmental conditions, and crop species, and that under certain circumstances, such treatments may not always produce positive vegetative responses.

4.4.3 Number of Flowers, Pods and Grains

There was a significant difference ($p < 0.05$) in the number of flowers, pods and grains in all cowpea varieties in trial I and II (Table 9). Application of goat manure and pearl millet mulch had a significant influence ($p < 0.05$) on number of flowers, pods and grains of cowpea varieties in both trials (Appendix 14, 15 and 16). The number of flowers, pods and grains increased from; control; pearl millet mulch; goat manure treatments in cowpea varieties in both trial I and II (Table 9). Number of flowers were slightly high in trial I (36.08) than trial II (35.58) under GM in M66 Variety while trial II had slightly higher number of pods (33.50) than trial I (33.08) in M66 at 56 DAS (Table 9). Number of grains were slightly high in trial II (18.33) than trial I under GM for M66 variety. In trial I and II M66 variety recorded highest number of flowers 36.08 and 35.58 in trial I and II, respectively at 49 DAS while under pearl millet mulch KVU 27-1 recorded 31.33 and 31.75 respectively, at 49 DAS (Table 9). Control recorded 14.58 and 14.67 in trial I and II respectively, at 49 DAS.

Table 9: Effects of Goat Manure and Pearl Millet Mulch on the Number of Flowers, Pods and Grains of Cowpea in Trials I and II

Trial	Cowpea Variety	Treatment	NOF42 DAS	NOF49 DAS	NOF56 DAS	NOP42 DAS	NOP49 DAS	NOP56 DAS	NOG75 DAS
I	K80	CONT	1.92^{a}	13.50^{a}	1.25^{a}	1.92^{a}	8.75^{a}	10.83^{a}	10.00^{a}
		GM	4.08^{bcd}	27.50^{cd}	3.58^{c}	6.50^{e}	20.25^{bcd}	28.08^{c}	17.08^{de}
		PMM	3.08^{bc}	22.25^{b}	4.75^{cd}	5.58^{d}	16.33^{bc}	26.25^{b}	13.42^{c}
	KVU 27-1	CONT	2.58^{b}	12.00^{a}	1.83^{a}	3.58^{c}	10.92^{a}	11.75^{a}	11.25^{a}
		GM	5.17^{de}	33.67^{cde}	4.42^{cd}	6.25^{e}	21.92^{bcd}	30.08^{cd}	16.25^{d}
		PMM	4.08^{bcd}	31.33^{cde}	6.42^{cde}	5.17^{d}	18.33^{bc}	26.08^{b}	14.92^{c}
	M66	CONT	2.92^{b}	14.58^{a}	2.58^{b}	2.25^{b}	12.33^{b}	12.92^{a}	12.08^{b}
		GM	6.33^{def}	36.08^{cdef}	4.83^{cd}	7.58^{ef}	25.00^{cdef}	33.08^{cde}	18.00^{def}
		PMM	4.67^{bcd}	24.92^{c}	8.17^{cdef}	5.50^{d}	20.67^{bcd}	30.50^{cd}	17.33^{de}
II	K80	CONT	1.75^{a}	13.58^{a}	1.17^{a}	1.92^{a}	8.92^{a}	11.00^{a}	10.08^{a}
		GM	5.08^{de}	27.50^{cd}	3.17^{c}	6.58^{e}	19.50^{bcd}	27.83^{b}	17.08^{de}
		PMM	3.33^{bc}	22.92^{b}	4.33^{cd}	5.58^{d}	16.33^{bc}	26.25^{b}	13.92^{c}
	KVU 27-1	CONT	2.25^{b}	12.25^{a}	1.83^{a}	3.67^{c}	11.25^{b}	11.92^{a}	11.17^{a}
		GM	5.33^{de}	34.00^{cde}	4.25^{cd}	6.33^{e}	22.25^{bcde}	30.08^{cd}	16.50^{d}
		PMM	4.50^{bcd}	31.75^{cde}	6.25^{cde}	5.33^{d}	18.58^{bc}	25.75^{b}	14.83^{c}
	M66	CONT	2.75^{b}	14.67^{a}	2.25^{b}	2.33^{b}	12.25^{b}	12.83^{a}	12.33^{b}
		GM	6.17^{def}	35.58^{cdef}	4.58^{cd}	7.75^{ef}	25.08^{cdef}	33.50^{cde}	18.33^{def}
		PMM	4.58^{bcd}	25.42^{c}	8.00^{cdef}	5.58^{d}	20.92^{bcd}	31.33^{cd}	17.17^{de}
		Mean	3.9210.	24.083	4.093	4.968	17.199	23.338	14.542
		CV (%)	12.4	2.7	13.2	10.9	5.1	2.4	4.0
		LSD$_{(0.05)}$	0.7819	1.0533	0.8748	0.8701	1.4213	0.9152	0.9495
		P-Value	0.001	0.001	0.001	0.001	0.001	0.001	0.001

Legend: CONT-control, CV (%) - Coefficient of variation, LSD-Least significance difference, GM-Goat Manure, PMM-Pearl Millet Mulch, DAS-Days after Sowing, NOF-Number of Flowers, NOP-Number of Pods and NOG-Number of Grains. Means with the same letters within the same column are not significantly different ($P < 0.05$).

In trial I M66 recorded the highest number of pods 33.08 and 33.50, pearl millet mulch 30.50 and 31.33, control 12.92 and 12.83 in trial I and II respectively, at 56 DAS (Table 9). There were increasing number of flowers and pods observed under treatments as days increased in both trials. In trial I and II, number of grains under goat manure were; 18.00 and 18.33, pearl millet mulch 17.33 and 17.17, control 12.08 and 12.33 at 75 DAS, respectively.

The number of flowers recorded after application of goat manure was 6.33, 36.08 and 4.83; 6.17, 35.58 and 4.58, pearl millet mulch 4.67, 31.33 and 8.17; 4.58,31.75 and 8.00, and control; 2.92, 14.58 and 2.58; 2.75, 14.67 and 2.25 at 42, 49 and 56 DAS in trial I and II, respectively (Table 9). Number of pods under application of goat manure had 7.58, 25.00 and 33.08; 7.75, 25.08 and 33.08; 7.75, 25.08 and 33.50, pearl millet mulch 5.58, 20.67 and 30.50; 5.58, 20.92 and 31.33, and control; 3.58, 12.33 and 12.92; 3.67, 12.25 and 12.83 at 42, 49 and 56 DAS, respectively in trial I and II respectively (Table 9). Number of grains recorded at harvesting was 18.00, 17.33 and 12.08 under goat manure, pearl millet mulch and control respectively, in trial I (Table 9). Numbers of grains recorded were 18.33, 17.17 and 12.33 under goat manure, pearl millet mulch and control at 75 DAS trial II (Table 9).

M66 cowpea variety had highest number flowers, pods and grains probably due to its deep root ability and fine roots to absorb available nutrients such as nitrogen, phosphorus and potation and micronutrients initiating more flowers. Also, its root system might have enhanced contact between nutrient and soil promoting uptake of nutrients and balancing of hormones, resulting to flower and pod formation as compared to KVU 27-1 and K80 with less root system and leaf surface areas.

The study indicates that the application of pearl millet stubble mulch and goat manure significantly enhanced the number of flowers, pods, and grains in pearl millet compared to the control. The high number of flowers, pods and grains due to goat manure was attributed to the high nutrients contained in the manure. Specifically, at 75 DAS, the number of grains was highest under goat manure (18.00 and 18.33 in trials I and II), followed by pearl millet mulch (17.33 and 17.17), while the control recorded the lowest (12.08 and 12.33). This suggests that organic amendments like goat manure and pearl millet stubble mulch promote better flowering and grain formation, likely due to enhanced soil fertility and moisture retention, thereby leading to higher yields compared to untreated conditions.

These findings concur with Rana and Roy (2024) who reported that goat manure contains nutrients such as, phosphorus that aid in transferring energy useful in flower formation and growth. It also contains potassium mineral that supports water uptake and nutrients transportation during flowering while calcium takes parts in cell division and cell wall formation during flowering. Zinc activates enzymes and regulation of hormones useful during flower formation. Magnesium synthesis chlorophyll playing roles in manufacturing photosynthates required for flowers, pods and grains formation and development. Phosphorus promotes cell division, which helps growth of flowers, pods and grains plants (Rana & Roy, 2024).

The application of pearl millet stubble mulch has been shown to positively influence reproductive parameters such as the number of flowers, pods, and grains in crops. Mulching with millet stubble helps conserve soil moisture, suppress weeds, and improve soil temperature regulation, which collectively create a favorable environment for flower and pod development (Giri *et al*., 2024). Additionally, the organic matter from millet stubble gradually decomposes, releasing essential nutrients that support reproductive growth and enhance photosynthetic efficiency (Choudhury & Choudhury, 2024). This improved resource availability often results in increased flower initiation, pod formation, and ultimately higher grain yield, as observed in various cropping systems. According to studies by Sarkar *et al*. (2020) the use of crop residues reduces the temperature by 10 °C in hot and dry soils, balancing metabolic regulations of plants, initiating and increasing the number of flowers, pods and grains.

Application of pearl millet stubble mulch may not always enhance reproductive parameters such as the number of flowers, pods, and grains. Prem *et al*. (2020) found that mulching with millet stubble in certain conditions could lead to increased soil moisture retention but also created a habitat conducive to pests and diseases, which negatively affected flowering and pod development. Moreover, excessive or improperly timed mulching has been associated with reduced oxygen diffusion to the roots, resulting in stress that can suppress reproductive growth (El-Beltagi *et al*., 2022).

The decomposition of millet stubble can sometimes lead to nitrogen immobilization, which may temporarily limit nutrient availability for flowering and pod formation (Taak *et al*., 2021).The findings of the study suggest that the benefits of millet stubble mulch are context-dependent and that under certain environmental or management conditions, its application may not result in the anticipated improvements in reproductive parameters. Before applying pearl millet stubble mulch therefore farmers are urged to conduct site-specific assessments, evaluate local environmental conditions and management practices to determine its suitability and potential effectiveness.

4.4.4 Effect of Goat Manure and Pearl Millet Stubble on Cowpea Grain Yield

There was a significant difference ($p < 0.05$) in the grain weight of the selected cowpea varieties in both trials (Table 10). Application of goat manure and pearl millet stubble mulch had significant influence ($p < 0.05$) on number grain weight in cowpea plants in trial I and II (Appendix 17). The grain yield increased from; control; pearl millet mulch; goat manure in cowpea varieties in trial I and II (Table 10). Grain yield mean was recorded as; 4625 kg/ha, 4292 kgs/ha and 2333 kgs/ha in trial I for M66 under goat manure, pearl millet mulch and control, respectively. Goat manure recorded the highest grain yield followed by pearl millet mulch and control with 4600 kg/ha, 4025 kg/ha, and 2500 kgs/ha respectively for trial II for M66 variety. M66 had the highest grain yield of 4625 kgs/ha, followed by K80 with 4375 kgs/ha and KVU-1 with 4167 kgs/acre.

Table 10: Effects of Goat Manure and Pearl Millet Stubble Mulch on Grain Weight of Cowpea Varieties

Trial	Cowpea Variety	Treatment	GWT kgs/ha
I	K80	CONT	1958[a]
		GM	4375[bc]
		PMM	3833[bc]
	KVU 27-1	CONT	2042[a]
		GM	4167[bc]
		PMM	4083[bc]
	M66	CONT	2333[a]
		GM	4625[c]
		PMM	4292[bc]
II	K80	CONT	2042[a]
		GM	4292[bc]
		PMM	3950[bc]
	KVU 27-1	CONT	2045[a]
		GM	4008[bc]
		PMM	3792[b]
	M66	CONT	2500[a]
		GM	4600[bc]
		PMM	4025[bc]
		Mean	3531
		CV (%)	7.2
		$LSD_{(0.05)}$	423.2
		P-Value	0.001

Legend: CV (%) - Coefficient of variation, LSD-Least significance difference, CONT-control, GM-Goat Manure, PMM-Pearl Millet Mulch, GWT-Grain weight

Grain weight yield of cowpeas was influenced significantly by the application of goat manure and pearl millet mulch at trial I and II. The application of goat manure and pearl millet mulch indicated their benefits for enhancing crop productivity. Goat manure recorded highest yield followed by pearl millet mulch and least was control.

M66 cowpea variety has deep root system with high capacity to convert nutrients into biomass by enhancing the process of photosynthesis probably favored by large surface area of the leaf with high chlorophyll content. Hence, using nutrients from goat manure, nitrogen promote vegetative growth, phosphorus strong root development and potassium boosts grain filling. This probably promote high efficiency of nutrient uptake exploiting necessary nutrients boosting higher yield than other varieties. Additionally, M66 variety with numerous fine roots it extracts more water from the soil enhancing nutrient absorption and translocation of assimilate to other part of the crop enhancing grain yield as compared to KVU 27-1 and K80. Hence, M66 might have realized highest grain yield due to pearl millet mulch and goat manure improving soil moisture and fertility ultimately improving performance of photosynthesis.

These findings align with those of Panda (2017) reported that goat manure application enhanced cowpea yields by improving soil fertility and plant growth parameters. Also, Kioko *et al*. (2024) observed green gram yields in Makueni were significantly higher when goat manure was applied compared to control plots with no organic amendments. They highlighted that manure contributed essential nutrients, particularly nitrogen, phosphorus, and organic matter, fostering optimal plant growth and pod development.

This evidence underscores the importance of integrating goat manure into sustainable smallholder farming systems to boost green gram productivity and ensure food security in the region. Pearl millet stubble mulch contributed to a grain yield increase, probably due to increases of moisture retention, reducing soil erosion through decreased detachment and runoff. The findings concur with El-Beltagi *et al*. (2022) noted pearl mulch intercepts raindrops, reducing their impact and enhancing water infiltration, drainage, and soil water retention factors that facilitate nutrient uptake, photosynthesis, and translocation of assimilates. These processes probably promoted plant growth and resulted to an increased grain yield. Overall, both amendments improve soil conditions and plant physiological processes, leading to higher crop yields.

However, the application of goat manure and pearl millet stubble mulch does not always lead to increased grain yields in cowpea (Prem *et al*., 2020). In certain cases, the use of goat manure has been associated with negligible or even negative effects on crop productivity, possibly due to issues such as nutrient imbalances, poor composting quality, or improper application rates (Prem *et al*., 2020). Excessive application of goat manure exceeds retention capacity of the soil nutrient resulting to nutrients dissolving with water leading to nutrients runoff and leaching, which may inhibit plant growth rather than promote it (Prem *et al*., 2020). Pearl millet stubble mulch has shown inconsistent results in some environments; instead of reducing soil erosion and improving water retention, it can sometimes create a physical barrier that impedes seedling emergence or alters soil temperature adversely (El-Beltagi *et al*., 2022). These contrasting outcomes highlight that the benefits of organic amendments like goat manure and millet mulch are highly context-dependent, influenced by factors such as soil type, climate conditions, and application methods. Therefore, under certain conditions, these practices may not yield the expected increases in cowpea grain weight and could even hinder crop development if not managed properly.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of the Findings

The study aimed at assessing the contribution of goat manure and pearl millet stubble mulch on soil moisture and fertility on selected cowpea varieties growth and yield under dryland conditions. Survey results were analysed using SPSS to determine current farming practices, varietal preferences, utilization patterns, production constraints, and the role of farmyard manure and stubble mulch in cowpea cultivation among farmers in Tharaka South Sub-County. Experimental results were derived by analysis of variance using SAS® 9.4 at 5% probability level to assess the effect of goat manure and pearl millet mulch application on selected cowpeas varieties on growth and yield in dryland areas. Least Significant Difference at $\alpha = 0.05$ was used to perform mean separation. Goat manure and pearl millet mulch showed significant difference on soil moisture content, soil chemical properties, plant height, stem girth, number of leaves, leaf area, number of branches, number of flowers, number of pods, number of grains and grain weight.

The survey data collected from 64 respondents revealed that majority (65%), were engaged in both crop and livestock production, and predominantly practicing mono cropping of cowpeas. Among the cowpea varieties cultivated, were M66 (44%), KVU 27-1 (36%), and K80 (14%). Many farmers sourced their cowpea seeds from previous harvests (62%), achieving an average yield between 100-200 kg (36%). A total of 95.5% of the respondents expressed dissatisfaction with these yields and 4.5% expressing satisfaction, primarily attributing their challenges to moisture stress (65.1%) and soil degradation (30.1%). The farmers identified the application of organic fertilizer and previous crop residues (67%) as key strategies for enhancing cowpea yields. Notably, 70% reported not applying previous crop residues and 30% applying, with 43.5% using the residues to feed livestock, while 34.8% burnt them. Among the livestock kept, goats were the most prevalent at 62%, followed by chickens at 20%. Although 30% of the respondents utilized livestock manure on their farms, a substantial 70% did not. Despite this, 90% of the farmers acknowledged the importance of manure for enhancing organic matter in the soil to improve fertility, while only 10% recognized its benefits for water infiltration and retention. Overall, the survey highlighted that low cowpea production was linked to poor seed selection from previous harvests, insufficient manure application, and the under-utilization of previous crop residues, despite the predominant raising of goats among the farmers.

The application of pearl millet mulch and goat manure had a significant effect on soil moisture content. Pearl millet mulch had a significant influence on soil moisture levels followed by goat manure and control with no inputs. The soil moisture levels exhibited a clear hierarchy, with pearl millet stubble mulch (PMM) providing the highest moisture retention, followed by goat manure (GM), and lastly the control. Highest moisture content was observed under pearl millet mulch with 25.77% and 28.03% at 21 and 7 DAS in trial I and II respectively. Goat manure recorded moisture content of 24.70% and 27.37% at both 7 DAS in both trials. Application of pearl millet mulch demonstrated a potential of retaining moisture.

The study revealed that both amendments, goat manure, pearl millet mulch significantly enhanced soil fertility, as indicated by the increase in soil pH, nitrogen (N), phosphorus (P), potassium (K), and carbon (C) levels, with the greatest improvements noted from goat manure compared to the control treatment. Goat manure exhibited N, C, K, and P concentrations of 0.69 %, 1.33%, 1.94 Cmol kg^{-1}, and 16.67 ppm, while pearl millet mulch demonstrated lower but significant levels at 0.16%, 1.21%, 1.41 Cmol kg^{-1}, and 12.48 ppm, respectively. These enhancements were consistent across various cowpea varieties in both trials. Application of both amendments significantly increased the levels of magnesium (Mg), calcium (Ca), iron (Fe), manganese (Mn), apart from copper (Cu) and Zinc (Zn). Application of goat manure and pearl millet mulch improved soil fertility.

The treatments, goat manure and pearl millet stubble mulch had influence on selected cowpea varieties growth and yield. The influence of pearl millet mulch was higher on plant height followed by goat manure and control which had minor effects. Higher influence was observed in stem girth, number of leaves, number of branches, leaf area, number of flowers, number of pods, number of grains and yield under goat manure application followed by pearl millet mulch and control across selected cowpea varieties in both trials I and II. Higher plant height 37.46 cm was realized under pearl millet application for M66 cowpea variety at 56 DAS under trial II. Stem girth, number of leaves, leaf area, number of branches, number of flowers, number of pods and grains were; 4.38, 42.58, 40.88, 7.75, 36.08, 33.50 and 18.33 at 56, 42, 49, 42, 49, 56 and 75 DAS under goat manure respectively in trial II except for leaf area and number of flowers that was high in trial I. High yield of 4625 kgs/ha was realized under goat manure in trial I for M66 cowpea variety and lowest 1958 kgs/ha for K80 variety under control.

5.2 Conclusion

Goat manure and pearl millet stubble mulch as organic amendments improved soil health, moisture retention, and cowpea productivity. Majority of farmers in the surveyed area were engaged in both crop and livestock production, with many facing challenges such as low yields and dissatisfaction due to moisture stress and soil degradation. By applying goat manure and pearl millet stubble mulch, there were noticeable improvements in key soil parameters, including nutrient levels and soil moisture content, which directly correlated with enhanced plant height, stem girth, and overall yield of cowpeas. From the findings of the study it can be concluded that goat manure and pearl millet mulch not only foster soil fertility but also mitigate moisture loss and enhance microbial activity, thereby supporting sustainable agricultural practices in arid and semi-arid environments. Therefore, this study advocates for the wider adoption of goat manure and pearl millet as organic amendments, which will encourage shift towards more sustainable farming practices that improve productivity and environmental health.

5.3 Recommendations

Based on the findings of this study, the following recommendations are proposed to enhance cowpea production and promote sustainable agricultural practices among farmers in arid and semi-arid lands:

i. Encourage farmers and agricultural extension officers to adopt the use of goat manure and pearl millet stubble mulch as organic soil amendments, as they significantly enhance soil fertility, moisture retention, and crop growth, leading to higher yields.

ii. Promote the selection and utilization of high-yielding cowpea varieties such as M66, which demonstrated superior growth and productivity under improved soil conditions, to maximize production potential.

5.4 Suggestions for Further Research

The study proposes that upcoming studies to:

i. Assess the effects of different rates of application of goat manure and pearl millet stubble mulch on growth and yield of cowpeas.
ii. Investigate the effects of integrating goat manure and pearl millet stubble mulch on growth of cowpeas.
iii. Conduct cost benefit analysis of using pearl millet biomass as mulch compared to using it as a livestock feed.

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APPENDICES

Appendix 1: Chuka Ethical Review Committee Clearance Letter

CHUKA UNIVERSITY

Knowledge is Wealth *(Sapientia divitia est)* Akili ni Mali

CHUKA UNIVERSITY INSTITUTIONAL ETHICS REVIEW COMMITTEE

Telephones: 020-2310512/18 P. O. Box 109-60400, Chuka
Direct Line: 0772894438 Email: info@chuka.ac.ke, Website: www.chuka.ac.ke

REF: CUIERC/ NACOSTI/402 **12th July, 2023**
TO: **Robert Gikunda Nthiga**

RE: Effect of Goat Manure and Pearl Millet Mulch on Selected Cowpea Varieties Growth and Yield in Tharaka South Sub-County

This is to inform you that *Chuka University IERC* has reviewed and approved your above research proposal. Your application approval number is *NACOSTI/NBC/AC-0812.* The approval period is 12th July, 2023 – 12th July, 2024.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *Chuka University IERC.*
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *Chuka University IERC* within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *Chuka University IERC* within 72 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to *Chuka University IERC.*

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely

Dr. Benjamin Kanga
SECRETARY

Chuka University is……. …Inspiring Environmental Sustainability for Better Life

Appendix 2: Nacosti Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 936401

Date of Issue: 02/August/2023

RESEARCH LICENSE

This is to Certify that Mr.. Robert Gikunda Nthiga of Chuka University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Tharaka-Nithi on the topic: Effect of Goat Manure and Pearl Millet Mulch on Selected Cowpea Varieties Growth and Yield in Tharaka South Sub-County for the period ending : 02/August/2024.

License No: NACOSTI/P/23/28324

936401

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.

See overleaf for conditions

Appendix 3: Acceptance to conduct field experiment at Tharaka University demonstration farm

THARAKA UNIVERSITY COLLEGE

P.O BOX 193-60215,
MARIMANTI, KENYA

Telephone :|+(254)-0202008549, +(254)-0202007692
Website: tharaka.ac.ke

THARAKA UNIVERSITY COLLEGE
Education for Freedom

(A Constituent College of Chuka University)
OFFICE OF THE REGISTRAR
(Administration and Planning)

REF: TUC/REG(A&P) LETT/001/2022 **18th January 2022**

ROBERT GIKUNDA NTHIGA
P.O BOX 42-60215
NKONDI, MARIMANTI
TEL:0705312725

Dear Mr. Robert

RE: REQUEST FOR AN EXPERIMENTAL PLOT

We acknowledge receipt of your letter dated **15th December 2021** on the above subject.

Tharaka University College Management has accepted your request. Therefore you are advised to consult the Registrar (Administration and Planning) for the allocation of the plot.

Thanks.

THARAKA UNIVERSITY COLLEGE
REGISTRAR
16 JAN 2022
REGISTRAR ADMINISTRATION AND PLANNING
P.O. Box 193 - 60215, MARIMANTI

Yours Sincerely,

Edward P.G Kathuni.
Ag. Registrar (Administration and Planning)

Appendix 4: Survey Questionnaire

A) IDENTIFICATION

Respondent……………………………………….

B) DEMOGRAPHICS AND HOUSEHOLD CHARACTERISTICS

No	Questions	Coding categories	Skip to
1	Gender	Female:.……………………………1 Male:………………………………..2	
2	What is your **main** occupation (select multiple)	Crop farming: ……………………...1 Livestock production:……………...2 Employed: ………………………....3 Business: ……..................................4 Casual labour:…………………......5	

C) CROP PRODUCTION AND MANAGEMENT

3	Which of the following agro-ecological farming practices do you undertake when growing cowpeas? 1. Crop rotation 2. Intercropping 3. Mono cropping 4. Others (specify)	
4a	What are the main cowpea varieties grown? 1. Katumani 2. Machakos 66 (M66) 3. KVU 27-1 4. Kunde mboga 5. Local Variety (LV) 6. Any other	
4b	Where do you source cowpea seeds? 1. Agrovet 2. Market 3. Previous harvest 4. NGOs 5. County government 6. Any other	
5a.	What is size of land under which cowpeas is grown? 1. Less than 1 acre 2. 1-2 acre 3. Above 2 acre	
5b.	What is the average yield of cowpeas per size of land mentioned above? 1. 0-100 kgs 2. 100-200 kgs 3. 200-300 kgs 4. 300-400 kgs	

	5. Above 400 kgs	
5c.	Are you satisfied with the yield obtained above? 1. Yes 2. No	
5d.	If No, what is the **main** challenge hindering optimum yield of cowpea? 1. Pests 2. Diseases 3. Moisture stress 4. Soil degradation 5. Using uncertified seeds 6. Any other (**Specify**)	
6.	What are the strategies that can be applied to improve yield of cowpeas? 1. Use of certified seeds 2. Application of organic fertilizer 3. Application of inorganic fertilizer 4. Use of previous crop residues 5. Any other	
7.	Do you apply your previous crop residue during land preparation? 1. Yes 2. No	
8a	If Yes, what is the **main** benefit of applying previous crop residues? 1. Increased moisture retention 2. Conserve soil 3. Add organic matter in the soil	
9b	If No, how do you use your previous crop residues? 1. Burn 2. Sell 3. Feed to livestock 4. Any other (Specify)	
10	What type of livestock do you **mainly** keep? 1. Goat 2. Cow 3. Chicken 4. Pig	
11	Do you use the manure from the livestock mentioned above? 1. Yes 2. No	
12	If yes, what is the main benefit of farmyard manure? 1. Add organic matter into the soil improving soil fertility 2. Improves water infiltration and soil moisture retention 3. Any other	
13a	Do you practice any soil moisture conservation measures on your farm?	

	1. Yes 2. No	
13b	If yes, Which ones? 1. Permanent soil cover 2. Conservation agriculture 3. Contour farming 4. Terraces (Fanya Juu, Fanya Chini, cut-off drains)	

Thank you for your attention

R1	V1				V2				V3		
	GM	PMM	CONT		PMM	GM	CONT		CONT	PMM	GM
R2	V3			50 cm	V1			50 cm	V2		
	CONT	GM	PMM		PMM	CONT	GM		PMM	GM	CONT
R3	V2				V3				V1		
	PMM	CONT	GM		CONT	GM	PMM		GM	PMM	CONT

Appendix 5: Experimental plot layout

LEGEND: CONT- Control, GM- Goat manure, PMM- Pearl millet stubble mulch, V1, V2, V3- Cowpea varieties

Appendix 6: ANOVA table for soil moisture content at 7, 14, 21, 28, 35, 42 and 49 DAS

Soil Moisture Content at 7 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.5270	0.2635	1.17	
Treatment	2	26.9004	13.4502	59.55	<.001
Variety	2	0.3404	0.1702	0.75	0.478
TRIAL	1	83.1296	83.1296	368.04	<.001
Treatment*Variety	4	0.2619	0.0655	0.29	0.883
Treatment*Trial	2	0.0159	0.0080	0.04	0.965
Variety*Trial	2	0.0093	0.0046	0.02	0.980
Treatment*Variety*Trial	4	0.2019	0.0505	0.22	0.923
Residual	34	7.6796	0.2259		
Total	53	119.0659			
Grand mean		25.837			
CV (%)		1.8			

Soil Moisture Content at 14 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.2711	0.1356	1.07	
Treatment	2	44.7344	22.3672	175.95	<.001
Variety	2	0.0544	0.0272	0.21	0.808
Trial	1	650.3474	650.3474	5115.84	<.001
Treatment*Variety	4	0.1378	0.0344	0.27	0.895
Treatment*Trial	2	3.2693	1.6346	12.86	<.001
Variety*Trial	2	0.3848	0.1924	1.51	0.235
Treatment*Variety*Trial	4	0.0319	0.0080	0.06	0.992
Residual	34	4.3222	0.1271		
Total	53	703.5533			
Grand Mean		21.356			
CV (%)		1.7			

Soil Moisture Content at 21 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.7526	0.3763	1.51	
Treatment	2	27.1915	13.5957	54.64	<.001
Variety	2	0.3293	0.1646	0.66	0.523
Trial	1	0.4091	0.4091	1.64	0.208
Treatment*Variety	4	0.5563	0.1391	0.56	0.694
Treatment*Trial	2	1.5404	0.7702	3.10	0.058
Variety*Trial	2	0.0493	0.0246	0.10	0.906
Treatment*Variety*Trial	4	0.5096	0.1274	0.51	0.727
Residual	34	8.4607	0.2488		
Total	53	39.7987			
Grand mean		24.676			
CV (%)		2.0			

Soil Moisture Content at 28 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.5626	0.2813	1.11	
Treatment	2	42.9048	21.4524	84.97	<.001
Variety	2	0.4637	0.2319	0.92	0.409
Trial	1	1102.5185	1102.5185	4366.88	<.001
Treatment*Variety	4	0.1741	0.0435	0.17	0.951
Treatment*Trial	2	2.0093	1.0046	3.98	0.028
Variety*Trial	2	0.1170	0.0585	0.23	0.794
Treatment*Variety*Trial	4	0.5785	0.1446	0.57	0.684
Residual	34	8.5841	0.2525		
Total	53	1157.9126			
Grand mean		20.070			
CV (%)		2.5			

Soil Moisture Content at 35 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.0744	0.0372	0.17	
Treatment	2	63.4978	31.7489	143.82	<.001
Variety	2	19.1111	9.5556	43.29	<.001
Trial	1	104.7230	104.7230	474.39	<.001
Treatment*Variety	4	3.1478	0.7869	3.56	0.016
Treatment*Trial	2	2.2993	1.1496	5.21	0.011
Variety*Trial	2	6.1170	3.0585	13.86	<.001
Treatment*Variety*Trial	4	1.9574	0.4894	2.22	0.088
Residual	34	7.5056	0.2208		
Total	53	208.4333			
Grand mean		16.344			
CV (%)		2.9			

Soil Moisture Content at 42 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	1.7226	0.8613	2.22	
Treatment	2	36.5348	18.2674	47.01	<.001
Variety	2	7.0093	3.5046	9.02	<.001
Trial	1	25.3519	25.3519	65.25	<.001
Treatment*Variety	4	2.6241	0.6560	1.69	0.175
Treatment*Trial	2	1.3170	0.6585	1.69	0.199
Variety*Trial	2	3.3737	1.6869	4.34	0.021
Treatment*Variety*Trial	4	1.3374	0.3344	0.86	0.497
Residual	34	13.2107	0.3886		
Total	53	92.4815			
Grand mean		15.081			
CV (%)		4.1			

Soil Moisture Content at 49 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.0448	0.0224	0.07	
Treatment	2	40.9604	20.4802	63.18	<.001
Variety	2	0.7159	0.3580	1.10	0.343
Trial	1	5.5424	5.5424	17.10	<.001
Treatment*Variety	4	0.4796	0.1199	0.37	0.828
Treatment*Trial	2	1.5737	0.7869	2.43	0.103
Variety*Trial	2	1.3448	0.6724	2.07	0.141
Treatment*Variety*Trial	4	1.6107	0.4027	1.24	0.312
Residual	34	11.0219	0.3242		
Total	53	63.2943			
Grand mean		13.946			
CV (%)		4.1			

Appendix 7: ANOVA Table for Soil Chemical Properties

Soil Reaction (PH)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.05848	0.02924	1.17	
Treatment	2	0.09434	0.04717	1.89	0.167
Variety	2	0.30271	0.15136	6.05	0.006
Trial	1	7.24534	7.24534	289.61	<.001
Treatment*Variety	4	0.14504	0.03626	1.45	0.239
Treatment*Trial	2	0.01789	0.00895	0.36	0.702
Variety*Trial	2	0.06161	0.03081	1.23	0.305
Treatment*Variety*Trial	4	0.13639	0.03410	1.36	0.267
Residual	34	0.85059	0.02502		
Total	53	8.91240			
Grand mean		7.023			
CV (%)		2.3			

Nitrogen (%)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.03990	0.01995	1.85	
Treatment	2	0.54698	0.27349	25.34	<.001
Variety	2	0.02271	0.01136	1.05	0.360
Trial	1	0.14107	0.14107	13.07	<.001
Treatment*Variety	4	0.07378	0.01844	1.71	0.171
Treatment*Trial	2	0.20253	0.10127	9.38	<.001
Variety*TRIAL	2	0.06084	0.03042	2.82	0.074
Treatment*Variety*Trial	4	0.14816	0.03704	3.43	0.018
Residual	34	0.36697	0.01079		
Total	53	1.60293			
Grand mean		0.206			
CV (%)		50.5			

Percentage Organic Carbon

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.00770	0.00385	0.19	
Treatment	2	4.97633	2.48817	125.16	<.001
Variety	2	0.29495	0.14748	7.42	0.002
Trial	1	0.57314	0.57314	28.83	<.001
Treatment*Variety	4	1.10114	0.27528	13.85	<.001
Treatment*Trial	2	3.64245	1.82123	91.61	<.001
Variety*Trial	2	0.47238	0.23619	11.88	<.001
Treatment*Variety*Trial	4	1.33798	0.33450	16.83	<.001
Residual	34	0.67592	0.01988		
Total	53	13.08200			
Grand mean		1.282			
CV (%)		11.0			

Calcium (Ca) Cmol_kg

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.0216	0.0108	0.07	
Treatment	2	5.6689	2.8344	19.34	<.001
Variety	2	3.5256	1.7628	12.03	<.001
Trial	1	130.1135	130.1135	887.58	<.001
Treatment*Variety	4	1.1875	0.2969	2.03	0.113
Treatment*Trial	2	3.8729	1.9365	13.21	<.001
Variety*Trial	2	0.7820	0.3910	2.67	0.084
Treatment*Variety*Trial	4	2.2345	0.5586	3.81	0.012
Residual	34	4.9842	0.1466		
Total	53	152.3906			
Grand mean		3.661			
CV (%)		10.5			

Potassium (K) Cmol_kg_

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.06000	0.03000	0.41	
Treatment	2	0.41610	0.20805	2.83	0.073
Variety	2	0.21026	0.10513	1.43	0.253
Trial	1	1.04611	1.04611	14.24	<.001
Treatment*Variety	4	0.09130	0.02282	0.31	0.869
Treatment*Trial	2	0.54316	0.27158	3.70	0.035
Variety*Trial	2	0.29832	0.14916	2.03	0.147
Treatment*Variety*Trial	4	0.13292	0.03323	0.45	0.770
Residual	34	2.49794	0.07347		
Total	53	5.29611			
Grand mean		1.277			
CV (%)		21.2			

Phosphorus (P) (ppm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	872.9	436.4	1.33	
Treatment	2	884.6	442.3	1.35	0.273
Variety	2	1012.1	506.0	1.55	0.228
Trial	1	119919.3	119919.3	366.26	<.001
Treatment*Variety	4	12464.9	3116.2	9.52	<.001
Treatment*Trial	2	757.8	378.9	1.16	0.326
Variety*Trial	2	657.3	328.6	1.00	0.377
Treatment*Variety*Trial	4	11769.3	2942.3	8.99	<.001
Residual	34	11132.0	327.4		
Total	53	159470.2			
Grand Mean		59.6			
CV (%)		30.4			

Magnesium (Mg) cmol_kg_

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.3398	0.1699	1.67	
Treatment	2	2.3732	1.1866	11.65	<.001
Variety	2	0.2724	0.1362	1.34	0.276
Trial	1	103.5043	103.5043	1016.43	<.001
Treatment*Variety	4	0.4596	0.1149	1.13	0.360
Treatment*Trial	2	0.3439	0.1720	1.69	0.200
Variety*Trial	2	0.1516	0.0758	0.74	0.483
Treatment*Variety*Trial	4	0.7768	0.1942	1.91	0.132
Residual	34	3.4623	0.1018		
Total	53	111.6838			
Grand Mean		2.315			
CV (%)		13.8			

Copper (Cu) (ppm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.14298	0.07149	1.24	
Treatment	2	0.05847	0.02923	0.51	0.606
Variety	2	0.16880	0.08440	1.47	0.245
Trial	1	0.83801	0.83801	14.58	<.001
Treatment*Variety	4	1.42165	0.35541	6.18	<.001
Treatment*Trial	2	0.44117	0.22058	3.84	0.031
Variety*Trial	2	1.33806	0.66903	11.64	<.001
Treatment*Variety*Trial	4	1.12916	0.28229	4.91	0.003
Residual	34	1.95432	0.05748		
Total	53	7.49260			
Grand Mean		1.365			
CV (%)		17.6			

Iron (Fe) (ppm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	389.3	194.7	1.30	
Treatment	2	1156.3	578.1	3.85	0.031
Variety	2	1056.9	528.5	3.52	0.041
Trial	1	40688.0	40688.0	271.22	<.001
Treatment*Variety	4	245.0	61.3	0.41	0.801
Treatment*Trial	2	545.8	272.9	1.82	0.178
Variety*Trial	2	830.4	415.2	2.77	0.077
Treatment*Variety*Trial	4	657.3	164.3	1.10	0.375
Residual	34	5100.7	150.0		
Total	53	50669.7			
Grand Mean		110.4			
CV (%)		11.1			

Manganese (Mn) (ppm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	42.9	21.5	0.13	
Treatment	2	2249.7	1124.9	6.98	0.003
Variety	2	978.5	489.2	3.04	0.061
Trial	1	3426.5	3426.5	21.26	<.001
Treatment*Variety	4	1763.0	440.7	2.73	0.045
Treatment*Trial	2	3566.2	1783.1	11.06	<.001
Variety*Trial	2	778.7	389.4	2.42	0.104
Treatment*Variety*Trial	4	339.7	84.9	0.53	0.717
Residual	34	5479.4	161.2		
Total	53	18624.6			
Grand Mean		114.8			
CV (%)		11.1			

Zinc (Zn) (ppm)

Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.17994	0.08997	0.93	
Treatment	2	0.94585	0.47292	4.89	0.014
Variety	2	0.07269	0.03635	0.38	0.690
Trial	1	6.63602	6.63602	68.62	<.001
Treatment*Variety	4	0.97024	0.24256	2.51	0.060
Treatment*Trial	2	0.39190	0.19595	2.03	0.147
Variety*Trial	2	0.23681	0.11841	1.22	0.307
Treatment*Variety*Trial	4	0.26912	0.06728	0.70	0.600
Residual	34	3.28780	0.09670		
Total	53	12.99036			
Grand Mean		3.277			
CV (%)		9.5			

Appendix 8: ANOVA Table for Plant Height at 14, 28, 42 and 56 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.09843	0.04921	3.92	
Treatment	2	773.95620	386.97810	30844.01	<.001
Variety	2	64.01398	32.00699	2551.11	<.001
Trial	1	0.89449	0.89449	71.30	<.001
Plant No	3	0.06236	0.02079	1.66	0.179
Treatment*Variety	4	7.06241	1.76560	140.73	<.001
Treatment*Trial	2	25.46954	12.73477	1015.02	<.001
Variety*Trial	2	1.03231	0.51616	41.14	<.001
Treatment*Plant No	6	0.05639	0.00940	0.75	0.611
Variety*Plant No	6	0.04417	0.00736	0.59	0.741
Trial*Plant No	3	0.03718	0.01239	0.99	0.401
Treatment*Variety*Trial	4	14.76574	3.69144	294.23	<.001
Treatment*Variety*Plant No	12	0.24833	0.02069	1.65	0.085
Treatment*Trial*Plant no	6	0.15269	0.02545	2.03	0.066
Variety*Trial*Plant no	6	0.04435	0.00739	0.59	0.739
Treatment*Variety*Trial*Plant No.	12	0.22870	0.01906	1.52	0.124
Residual	142	1.78157	0.01255		

Total	215	889.94884			
Grand Mean		8.0977			
CV (%)		1.4			

Plant Height at 28 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	6.8004	3.4002	8.64	
Treatment	2	2089.6173	1044.8087	2654.41	<.001
Variety	2	900.0562	450.0281	1143.33	<.001
Trial	1	3.0817	3.0817	7.83	0.006
Plant No	3	0.1515	0.0505	0.13	0.943
Treatment*Variety	4	208.5180	52.1295	132.44	<.001
Treatment*Trial	2	26.5636	13.2818	33.74	<.001
Variety*Trial	2	17.6308	8.8154	22.40	<.001
Treatment*Plant No	6	0.0760	0.0127	0.03	1.000
Variety*Plant No	6	0.9138	0.1523	0.39	0.886
Trial*Plant No	3	0.1869	0.0623	0.16	0.924
Treatment*Variety*Trial	4	15.9839	3.9960	10.15	<.001
Treatment*Variety*Plant No	12	1.2620	0.1052	0.27	0.993
Treatment*Trial*Plant No	6	0.2401	0.0400	0.10	0.996
Variety*Trial*Plant No	6	0.8251	0.1375	0.35	0.909
Treatment*Variety*Trial*Plant No	12	2.2946	0.1912	0.49	0.920
Residual	142	55.8930	0.3936		
Total	215	3330.0948			
Grand Mean		13.326			
CV (%)		4.7			

Plant Height 42 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	4.6004	2.3002	2.67	
Treatment	2	4163.6305	2081.8152	2415.69	<.001
Variety	2	1335.4216	667.7108	774.80	<.001
Trial	1	9.2628	9.2628	10.75	0.001
Plant No	3	1.6307	0.5436	0.63	0.596
Treatment*Variety	4	1089.0365	272.2591	315.92	<.001
Treatment*Trial	2	2.4915	1.2457	1.45	0.239
Variety*Trial	2	4.6153	2.3076	2.68	0.072
Treatment*Plant No	6	7.2205	1.2034	1.40	0.220
Variety*Plant No	6	6.4394	1.0732	1.25	0.287
Trial*Plant No	3	1.7131	0.5710	0.66	0.576
Treatment*Variety*Trial	4	6.1569	1.5392	1.79	0.135
Treatment*Variety*Plant No	12	7.8233	0.6519	0.76	0.694
Treatment*Trial*Plant No	6	2.5858	0.4310	0.50	0.807
Variety*Trial*Plant No	6	2.7717	0.4620	0.54	0.780
Treatment*Variety*Trial*Plant No	12	8.9004	0.7417	0.86	0.588
Residual	142	122.3742	0.8618		
Total	215	6776.6745			
Grand Mean		17.017			
CV (%)		5.5			

Plant Height at 56 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	19.308	9.654	4.62	
Treatment	2	4078.117	2039.059	975.19	<.001
Variety	2	2228.850	1114.425	532.98	<.001
Trial	1	82.634	82.634	39.52	<.001
Plant No	3	0.082	0.027	0.01	0.998
Treatment*Variety	4	1913.365	478.341	228.77	<.001
Treatment*Trial	2	3.086	1.543	0.74	0.480
Variety*Trial	2	2.243	1.122	0.54	0.586
Treatment*Plant	6	0.713	0.119	0.06	0.999
Variety*Plant No	6	0.878	0.146	0.07	0.999
Trial*Plant No	3	0.486	0.162	0.08	0.972
Treatment*Variety*Trial	4	9.122	2.281	1.09	0.364
Treatment*Variety*Plant No	12	3.636	0.303	0.14	1.000
Treatment*Trial*Plant No	6	0.559	0.093	0.04	1.000
Variety*Trial*Plant No	6	1.428	0.238	0.11	0.995
Treatment*Variety*Trial*Plant No	12	2.430	0.203	0.10	1.000
Residual	142	296.912	2.091		
Total	215	8643.851			
Grand Mean		20.756			
CV (%)		7.0			

Appendix 9: ANOVA Table for Stem Girth at 14, 28, 42 and 56 DAS

Stem Girth at 14 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.006759	0.003380	0.84	
Treatment	2	4.877315	2.438657	604.09	<.001
Variety	2	0.117037	0.058519	14.50	<.001
Trial	1	0.005602	0.005602	1.39	0.241
Plant No	3	0.026806	0.008935	2.21	0.089
Treatment*Variety	4	0.088519	0.022130	5.48	<.001
Treatment*Trial	2	0.003426	0.001713	0.42	0.655
Variety*Trial	2	0.002593	0.001296	0.32	0.726
Treatment*Plant No	6	0.040833	0.006806	1.69	0.129
Variety*Plant No	6	0.015556	0.002593	0.64	0.696
Trial*Plant No	3	0.000139	0.000046	0.01	0.998
Treatment*Variety*Trial	4	0.002963	0.000741	0.18	0.947
Treatment*Variety*Plant No	12	0.048889	0.004074	1.01	0.444
Treatment*Trial*Plant No	6	0.003611	0.000602	0.15	0.989
Variety*Trial*Plant No	6	0.001111	0.000185	0.05	1.000
Treatment*Variety*Trial*Plant No	12	0.005556	0.000463	0.11	1.000
Residual	142	0.573241	0.004037		
Total	215	5.819954			
Grand Mean		1.0755			
CV (%)		5.9			

Stem Girth at 28 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.02861	0.01431	1.02	
Treatment	2	34.91028	17.45514	1244.67	<.001
Variety	2	19.78111	9.89056	705.27	<.001
Trial	1	0.01852	0.01852	1.32	0.252
Plant No	3	0.08648	0.02883	2.06	0.109
Treatment*Variety	4	1.45111	0.36278	25.87	<.001
Treatment*Trial	2	0.01231	0.00616	0.44	0.646
Variety*Trial	2	0.05815	0.02907	2.07	0.130
Treatment*Plant No	6	0.17824	0.02971	2.12	0.055
Variety*Plant No	6	0.16852	0.02809	2.00	0.069
Trial*Plant No	3	0.02519	0.00840	0.60	0.617
Treatment*Variety*Trial	4	0.00519	0.00130	0.09	0.985
Treatment*Variety*Plant No	12	0.46926	0.03910	2.79	0.002
Treatment*Trial*Plant No	6	0.01620	0.00270	0.19	0.978
Variety*Trial*Plant No	6	0.01815	0.00302	0.22	0.971
Treatment*Variety*Trial*Plant No	12	0.01963	0.00164	0.12	1.000
Residual	142	1.99139	0.01402		
Total	215	59.23833			
Grand Mean		1.9806			
CV (%)		6.0			

Stem Girth at 42 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.095093	0.047546	10.47	
Treatment	2	35.121204	17.560602	3866.61	<.001
Variety	2	61.618148	30.809074	6783.75	<.001
Trial	1	0.003750	0.003750	0.83	0.365
Plant No	3	0.009769	0.003256	0.72	0.543
Treatment*Variety	4	15.358241	3.839560	845.42	<.001
Treatment*Trial	2	0.015833	0.007917	1.74	0.179
Variety*Trial	2	0.031111	0.015556	3.43	0.035
Treatment*Plant No	6	0.017315	0.002886	0.64	0.702
Variety*Plant No	6	0.034815	0.005802	1.28	0.271
Trial*Plant No	3	0.001620	0.000540	0.12	0.949
Treatment*Variety*Trial	4	0.021389	0.005347	1.18	0.323
Treatment*Variety*Plant No	12	0.017685	0.001474	0.32	0.984
Treatment*Trial*Plant No	6	0.009352	0.001559	0.34	0.913
Variety*Trial*Plant No	6	0.019630	0.003272	0.72	0.634
Treatment*Variety*Trial*Plant No	12	0.018981	0.001582	0.35	0.978
Residual	142	0.644907	0.004542		
Total	215	113.038843			
Grand Mean		2.5227			
CV (%)		2.7			

Stem Girth at 56 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	1.28176	0.64088	18.73	
Treatment	2	48.94620	24.47310	715.32	<.001
Variety	2	44.84954	22.42477	655.45	<.001
Trial	1	0.00463	0.00463	0.14	0.714
Plant No	3	0.01093	0.00364	0.11	0.956
Treatment*Variety	4	10.56296	2.64074	77.19	<.001
Treatment*Trial	2	0.00565	0.00282	0.08	0.921
Variety*Trial	2	0.00176	0.00088	0.03	0.975
Treatment*Plant No	6	0.01935	0.00323	0.09	0.997
Variety*Plant No	6	0.03269	0.00545	0.16	0.987
Trial*Plant No	3	0.00944	0.00315	0.09	0.964
Treatment*Variety*Trial	4	0.05963	0.01491	0.44	0.783
Treatment*Variety*Plant No	12	0.03037	0.00253	0.07	1.000
Treatment*Trial*Plant No	6	0.01917	0.00319	0.09	0.997
Variety*Trial*Plant No	6	0.01306	0.00218	0.06	0.999
Treatment*Variety*Trial*Plant No	12	0.03667	0.00306	0.09	1.000
Residual	142	4.85824	0.03421		
Total	215	110.74204			
Grand Mean		2.779			
CV (%)		6.7			

Appendix 10: ANOVA table for number of leaves at 14, 28, 42 and 56 DAS

Number of Leaves at 14 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.3426	0.1713	1.70	
Treatment	2	94.0370	47.0185	466.11	<.001
Variety	2	1.6759	0.8380	8.31	<.001
Trial	1	0.0741	0.0741	0.73	0.393
Plant No	3	0.5556	0.1852	1.84	0.143
Treatment*Variety	4	1.5185	0.3796	3.76	0.006
Treatment*Trial	2	0.4815	0.2407	2.39	0.096
Variety*Trial	2	0.5648	0.2824	2.80	0.064
Treatment*Plant No	6	0.3333	0.0556	0.55	0.769
Variety*Plant No	6	0.5833	0.0972	0.96	0.452
Trial*Plant No	3	0.4074	0.1358	1.35	0.262
Treatment*Variety*Trial	4	0.6296	0.1574	1.56	0.188
Treatment*Variety*Plant No	12	0.7778	0.0648	0.64	0.803
Treatment*Trial*Plant No	6	0.2593	0.0432	0.43	0.859
Variety*Trial*Plant No	6	0.2870	0.0478	0.47	0.827
Treatment*Variety*Trial*Plant No	12	1.9630	0.1636	1.62	0.092
Residual	142	14.3241	0.1009		
Total	215	118.8148			
Grand Mean		2.926			
CV (%)		10.9			

Number of Leaves at 28 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	7.5278	3.7639	10.06	
Treatment	2	814.6944	407.3472	1088.53	<.001
Variety	2	248.6944	124.3472	332.29	<.001
Trial	1	3.6296	3.6296	9.70	0.002
Plant No	3	0.5370	0.1790	0.48	0.698
Treatment*Variety	4	119.1944	29.7986	79.63	<.001
Treatment*Trial	2	0.1204	0.0602	0.16	0.852
Variety*Trial	2	0.6204	0.3102	0.83	0.439
Treatment*Plant No	6	1.8241	0.3040	0.81	0.562
Variety*Plant No	6	0.9352	0.1559	0.42	0.867
Trial*Plant No	3	0.5556	0.1852	0.49	0.686
Treatment*Variety*Trial	4	0.3796	0.0949	0.25	0.907
Treatment*Variety*Plant No	12	3.2870	0.2739	0.73	0.718
Treatment*Trial*Plant No	6	1.3611	0.2269	0.61	0.725
Variety*Trial*Plant No	6	0.6389	0.1065	0.28	0.944
Treatment*Variety*Trial*Plant No	12	0.6944	0.0579	0.15	1.000
Residual	142	53.1389	0.3742		
Total	215	1257.8333			
Grand Mean		10.028			
CV (%)		6.1			

Number of Leaves at 42 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.8611	0.4306	0.63	
Treatment	2	8699.2500	4349.6250	6358.39	<.001
Variety	2	5064.6944	2532.3472	3701.85	<.001
Trial	1	0.2963	0.2963	0.43	0.512
Plant No	3	2.8519	0.9506	1.39	0.248
Treatment*Variety	4	249.3056	62.3264	91.11	<.001
Treatment*Trial	2	4.2870	2.1435	3.13	0.047
Variety*Trial	2	1.5093	0.7546	1.10	0.335
Treatment*Plant No	6	4.1204	0.6867	1.00	0.425
Variety*Plant No	6	2.0093	0.3349	0.49	0.815
Trial*Plant No	3	0.1852	0.0617	0.09	0.965
Treatment*Variety*Trial	4	4.1574	1.0394	1.52	0.200
Treatment*Variety*Plant No	12	6.4352	0.5363	0.78	0.666
Treatment*Trial*Plant No	6	1.4537	0.2423	0.35	0.906
Variety*Trial*Plant No	6	0.6759	0.1127	0.16	0.986
Treatment*Variety*Trial*Plant No	12	2.7685	0.2307	0.34	0.981
Residual	142	97.1389	0.6841		
Total	215	14142.0000			
Grand Mean		28.833			
CV (%)		2.9			

Number of Leaves at 56 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.954	0.477	0.39	
Treatment	2	5210.398	2605.199	2137.80	<.001
Variety	2	2210.954	1105.477	907.14	<.001
Trial	1	140.167	140.167	115.02	<.001
Plant No	3	7.315	2.438	2.00	0.117
Treatment*Variety	4	75.435	18.859	15.48	<.001
Treatment*Trial	2	41.194	20.597	16.90	<.001
Variety*Trial	2	42.528	21.264	17.45	<.001
Treatment*Plant No	6	1.269	0.211	0.17	0.984
Variety*Plant No	6	5.046	0.841	0.69	0.658
Trial*Plant No	3	1.093	0.364	0.30	0.826
Treatment*Variety*Trial	4	227.361	56.840	46.64	<.001
Treatment*Variety*Plant No	12	7.120	0.593	0.49	0.920
Treatment*Treatment*Plant No	6	2.546	0.424	0.35	0.910
Variety*Trial*Plant No	6	1.102	0.184	0.15	0.989
Treatment*Variety*Trial*Plant No	12	9.343	0.779	0.64	0.806
Residual	142	173.046	1.219		
Total	215	8156.870			
Grand Mean		23.620			
CV (%)		4.7			

Appendix 11: ANOVA Table for Leaf Area at 49 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	25.611	12.805	4.43	
Treatment	2	6035.338	3017.669	1044.82	<.001
Variety	2	7291.257	3645.629	1262.24	<.001
Trial	1	0.387	0.387	0.13	0.715
Plant No	3	0.831	0.277	0.10	0.962
Treatment*Variety	4	1049.559	262.390	90.85	<.001
Treatment*Trial	2	3.805	1.903	0.66	0.519
Variety*Trial	2	19.335	9.667	3.35	0.038
Treatment*Plant No	6	32.992	5.499	1.90	0.084
Variety*Plant No	6	36.506	6.084	2.11	0.056
Trial*Plant No	3	3.617	1.206	0.42	0.741
Treatment*Variety*Trial	4	13.349	3.337	1.16	0.333
Treatment*Variety*Plant No	12	40.665	3.389	1.17	0.308
Treatment*Trial*Plant No	6	2.110	0.352	0.12	0.994
Variety*Trial*Plant No	6	6.311	1.052	0.36	0.901
Treatment*Variety*Trial*Plant No	12	2.951	0.246	0.09	1.000
Residual	142	410.129	2.888		
Total	215	14974.752			
Grand Mean		23.42			
CV (%)		7.3			

Appendix 12: ANOVA Table for Leaf Area Index at 49 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.0013026	0.0006513	2.77	
Treatment	2	0.0020053	0.0010026	4.26	0.016
Variety	2	0.0135881	0.0067941	28.88	<.001
Trial	1	0.0018769	0.0018769	7.98	0.005
Plant No	3	0.0001594	0.0000531	0.23	0.878
Treatment*Variety	4	0.0122982	0.0030745	13.07	<.001
Treatment*Trial	2	0.0004145	0.0002073	0.88	0.417
Variety*Trial	2	0.0017007	0.0008504	3.61	0.029
Treatment*Plant No	6	0.0034145	0.0005691	2.42	0.030
Variety*Plant No	6	0.0036005	0.0006001	2.55	0.022
Trial*Plant No	3	0.0002133	0.0000711	0.30	0.824
Treatment*Variety*Trial	4	0.0005464	0.0001366	0.58	0.677
Treatment*Variety*Plant No	12	0.0066328	0.0005527	2.35	0.009
Treatment*Trial*Plant No	6	0.0003479	0.0000580	0.25	0.960
Variety*Trial*Plant No	6	0.0006800	0.0001133	0.48	0.821
Treatment*Variety*Trial*Plant No	12	0.0007448	0.0000621	0.26	0.994
Residual	142	0.0334110	0.0002353		
Total	215	0.0829369			
Grand Mean		0.1131			
CV (%)		13.6			

Appendix 13: ANOVA table for number of branches at 28, 42 and 56 DAS

Number of Branches 28 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.8426	0.4213	2.83	
Treatment	2	100.3981	50.1991	336.92	<.001
Variety	2	8.8981	4.4491	29.86	<.001
Trial	1	0.0741	0.0741	0.50	0.482
Plant No	3	0.7593	0.2531	1.70	0.170
Treatment*Variety	4	7.8796	1.9699	13.22	<.001
Treatment*Trial	2	0.0648	0.0324	0.22	0.805
Variety*Trial	2	0.0648	0.0324	0.22	0.805
Treatment*Plant No	6	1.6019	0.2670	1.79	0.105
Variety*Plant No	6	0.7685	0.1281	0.86	0.526
Trial*Plant No	3	0.0370	0.0123	0.08	0.969
Treatment*Variety*Trial	4	0.2130	0.0532	0.36	0.839
Treatment*Variety*Plant No	12	7.4537	0.6211	4.17	<.001
Treatment*Trial*Plant No	6	0.1574	0.0262	0.18	0.983
Variety*Trial*Plant No	6	0.0463	0.0077	0.05	0.999
Treatment*Variety*Trial*Plant No	12	0.6759	0.0563	0.38	0.969
Residual	142	21.1574	0.1490		
Total	215	151.0926			
Grand Mean		3.435			
CV (%)		11.2			

Number of Branches 42 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	2.3333	1.1667	4.64	
Treatment	2	196.1944	98.0972	390.56	<.001
Variety	2	60.1111	30.0556	119.66	<.001
Trial	1	3.3750	3.3750	13.44	<.001
Plant No	3	6.0139	2.0046	7.98	<.001
Treatment*Variety	4	31.5278	7.8819	31.38	<.001
Treatment*Trial	2	0.5833	0.2917	1.16	0.316
Variety*Trial	2	0.4444	0.2222	0.88	0.415
Treatment*Plant No	6	0.6944	0.1157	0.46	0.836
Variety*Plant No	6	1.8889	0.3148	1.25	0.283
Trial*Plant No	3	0.1620	0.0540	0.22	0.886
Treatment*Variety*Trial	4	0.1389	0.0347	0.14	0.968
Treatment*Variety*Plant No	12	3.6944	0.3079	1.23	0.271
Treatment*Trial*Plant No	6	0.8241	0.1373	0.55	0.772
Variety*Trial*Plant No	6	0.7407	0.1235	0.49	0.814
Treatment*Variety*Trial*Plant No	12	0.5648	0.0471	0.19	0.999
Residual	142	35.6667	0.2512		
Total	215	344.9583			
Grand Mean		5.014			
CV (%)		10.0			

Number of Branches 56 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	22.4537	11.2269	31.75	
Treatment	2	283.9537	141.9769	401.50	<.001
Variety	2	34.6204	17.3102	48.95	<.001
Trial	1	1.0417	1.0417	2.95	0.088
Plant No	3	0.3102	0.1034	0.29	0.831
Treatment*Variety	4	4.8241	1.2060	3.41	0.011
Treatment*Trial	2	0.1944	0.0972	0.27	0.760
Variety*Trial	2	0.0833	0.0417	0.12	0.889
Treatment*Plant No	6	1.2315	0.2052	0.58	0.745
Variety*Plant No	6	2.3426	0.3904	1.10	0.363
Trial*Plant No	3	0.7917	0.2639	0.75	0.526
Treatment*Variety*Trial	4	0.1389	0.0347	0.10	0.983
Treatment*Variety*Plant No	12	6.9907	0.5826	1.65	0.085
Treatment*Trial*Plant No	6	0.6944	0.1157	0.33	0.922
Variety*Trial*Plant No	6	0.3611	0.0602	0.17	0.984
Treatment*Variety*Trial*Plant No	12	1.5278	0.1273	0.36	0.975
Residual	142	50.2130	0.3536		
Total	215	411.7731			
Grand Mean		5.532			
CV (%)		10.7			

Appendix 14: ANOVA Table for Number of Flowers at 42, 49 and 56 DAS

Number of Flowers 42 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.0093	0.0046	0.02	
Treatment	2	325.5648	162.7824	693.65	<.001
Variety	2	67.1481	33.5741	143.07	<.001
Trial	1	0.5602	0.5602	2.39	0.125
Plant No	3	0.9028	0.3009	1.28	0.283
Treatment*Variety	4	5.0741	1.2685	5.41	<.001
Treatment*Trial	2	3.0093	1.5046	6.41	0.002
Variety*Trial	2	2.2593	1.1296	4.81	0.009
Treatment*Plant No	6	2.8056	0.4676	1.99	0.071
Variety*Plant No	6	1.4444	0.2407	1.03	0.411
Trial*Plant No	3	1.4583	0.4861	2.07	0.107
Treatment*Variety*Trial	4	2.9630	0.7407	3.16	0.016
Treatment*Variety*Plant No	12	0.8889	0.0741	0.32	0.986
Treatment*Trial*Plant No	6	0.9167	0.1528	0.65	0.689
Variety*Trial*Plant No	6	1.8889	0.3148	1.34	0.243
Treatment*Variety*Trial*Plant No	12	3.4444	0.2870	1.22	0.273
Residual	142	33.3241	0.2347		
Total	215	453.6620			
Grand Mean		3.921			
CV (%)		12.4			

Number of Flowers 49 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	21.5278	10.7639	25.28	
Treatment	2	13534.0833	6767.0417	15890.27	<.001
Variety	2	906.7500	453.3750	1064.61	<.001
Trial	1	2.2407	2.2407	5.26	0.023
Plant No	3	0.7593	0.2531	0.59	0.620
Treatment*Variety	4	1097.6667	274.4167	644.38	<.001
Treatment*Trial	2	3.1759	1.5880	3.73	0.026
Variety*Trial	2	0.8981	0.4491	1.05	0.351
Treatment*Plant No	6	5.3241	0.8873	2.08	0.059
Variety*Plant No	6	5.2130	0.8688	2.04	0.064
Trial*Plant No	3	0.4630	0.1543	0.36	0.780
Treatment*Variety*Trial	4	1.5185	0.3796	0.89	0.471
Treatment*Variety*Plant No	12	15.3704	1.2809	3.01	<.001
Treatment*Trial*Plant No	6	3.1204	0.5201	1.22	0.299
Variety*Trial*Plant No	6	1.5093	0.2515	0.59	0.737
Treatment*Variety*Trial*Plant No	12	2.4074	0.2006	0.47	0.929
Residual	142	60.4722	0.4259		
Total	215	15662.5000			
Grand Mean		24.083			
CV (%)		2.7			

Number of Flowers 56 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	0.9537	0.4769	1.62	
Treatment	2	729.2315	364.6157	1241.23	<.001
Variety	2	148.6204	74.3102	252.97	<.001
Trial	1	2.6667	2.6667	9.08	0.003
Plant No	3	1.6667	0.5556	1.89	0.134
Treatment*Variety	4	42.1296	10.5324	35.85	<.001
Treatment*Trial	2	0.1944	0.0972	0.33	0.719
Variety*Trial	2	0.3611	0.1806	0.61	0.542
Treatment*Plant No	6	1.9167	0.3194	1.09	0.373
Variety*Plant No	6	2.7500	0.4583	1.56	0.163
Trial*Plant No	3	1.1481	0.3827	1.30	0.276
Treatment*Variety*Trial	4	0.4444	0.1111	0.38	0.824
Treatment*Variety*Plant No	12	2.1667	0.1806	0.61	0.827
Treatment*Trial*Plant No	6	1.5463	0.2577	0.88	0.513
Variety*Trial*Plant No	6	0.7130	0.1188	0.40	0.875
Treatment*Variety*Trial*Plant No	12	1.9259	0.1605	0.55	0.881
Residual	142	41.7130	0.2938		
Total	215	980.1481			
Grand Mean		4.093			
CV (%)		13.2			

Appendix 15: ANOVA table for number of pods at 42, 49 and 56 DAS

Number of Pods 42 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	1.3981	0.6991	2.41	
Treatment	2	667.7870	333.8935	1148.89	<.001
Variety	2	9.3426	4.6713	16.07	<.001
Trial	1	0.3750	0.3750	1.29	0.258
Plant No	3	0.0880	0.0293	0.10	0.959
Treatment*Variety	4	56.6852	14.1713	48.76	<.001
Treatment*Trial	2	0.0278	0.0139	0.05	0.953
Variety*Trial	2	0.0833	0.0417	0.14	0.867
Treatment*Plant No	6	1.5093	0.2515	0.87	0.522
Variety*Plant No	6	3.7315	0.6219	2.14	0.052
Trial*Plant No	3	0.3843	0.1281	0.44	0.724
Treatment*Variety*Trial	4	0.0556	0.0139	0.05	0.996
Treatment*Variety*Plant No	12	7.1296	0.5941	2.04	0.024
Treatment*Trial*Plant No	6	0.6019	0.1003	0.35	0.912
Variety*Trial*Plant No	6	0.1019	0.0170	0.06	0.999
Treatment*Variety*Trial*Plant No	12	0.2037	0.0170	0.06	1.000
Residual	142	41.2685	0.2906		
Total	215	790.7731			
Grand Mean		4.968			
CV (%)		10.9			

Number of Pods 49 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	8.5648	4.2824	5.52	
Treatment	2	5032.5093	2516.2546	3245.25	<.001
Variety	2	684.7037	342.3519	441.54	<.001
Trial	1	0.2269	0.2269	0.29	0.589
Plant No	3	0.6435	0.2145	0.28	0.842
Treatment*Variety	4	24.4352	6.1088	7.88	<.001
Treatment*Trial	2	0.8426	0.4213	0.54	0.582
Variety*Trial	2	2.2593	1.1296	1.46	0.236
Treatment*Plant No	6	1.7870	0.2978	0.38	0.888
Variety*Plant No	6	0.8148	0.1358	0.18	0.983
Trial*Plant No	3	0.5324	0.1775	0.23	0.876
Treatment*Variety*Trial	4	2.3796	0.5949	0.77	0.548
Treatment*Variety*Plant No	12	4.3796	0.3650	0.47	0.929
Treatment*Trial*Plant No	6	0.5648	0.0941	0.12	0.994
Variety*Trial*Plant No	6	1.0370	0.1728	0.22	0.969
Treatment*Variety*Trial*Plant No	12	2.6574	0.2215	0.29	0.991
Residual	142	110.1019	0.7754		
Total	215	5878.4398			
Grand Mean		17.199			
CV (%)		5.1			

Number of Pods 56 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	7.6759	3.8380	11.94	
Treatment	2	14463.3981	7231.6991	22491.45	<.001
Variety	2	629.0648	314.5324	978.23	<.001
Trial	1	0.5602	0.5602	1.74	0.189
Plant No	3	1.0139	0.3380	1.05	0.372
Treatment*Variety	4	138.1574	34.5394	107.42	<.001
Treatment*Trial	2	0.1204	0.0602	0.19	0.829
Variety*Trial	2	2.2315	1.1157	3.47	0.034
Treatment*Plant No	6	0.7500	0.1250	0.39	0.885
Variety*Plant No	6	0.9722	0.1620	0.50	0.805
Trial*Plant No	3	0.1620	0.0540	0.17	0.918
Treatment*Variety*Trial	4	3.7130	0.9282	2.89	0.025
Treatment*Variety*Plant No	12	2.1389	0.1782	0.55	0.875
Treatment*Trial*Plant No	6	1.4352	0.2392	0.74	0.615
Variety*Trial*Plant No	6	0.3241	0.0540	0.17	0.985
Treatment*Variety*Trial*Plant No	12	0.9537	0.0795	0.25	0.995
Residual	142	45.65724	0.3215		
Total	215	15298.3287			
Grand Mean		23.338			
CV (%)		2.4			

Appendix 16: ANOVA Table for Number of Grains at 75 DAS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	10.1944	5.0972	14.73	
Treatment	2	1376.4444	688.2222	1988.80	<.001
Variety	2	203.1111	101.5556	293.47	<.001
Trial	1	0.7824	0.7824	2.26	0.135
Plant No	3	0.4213	0.1404	0.41	0.749
Treatment*Variety	4	51.9444	12.9861	37.53	<.001
Treatment*Trial	2	0.1481	0.0741	0.21	0.808
Variety*Trial	2	0.2593	0.1296	0.37	0.688
Treatment*Plant No	6	0.8148	0.1358	0.39	0.883
Variety*Plant no	6	0.9259	0.1543	0.45	0.847
Trial*Plant No	3	0.0509	0.0170	0.05	0.986
Treatment*Variety*Trial	4	2.0185	0.5046	1.46	0.218
Treatment*Variety*Plant No	12	2.4630	0.2052	0.59	0.845
Treatment*Trial*Plant No	6	1.4074	0.2346	0.68	0.668
Variety*Trial*Plant No	6	0.9630	0.1605	0.46	0.834
Treatment*Variety*Trial*Plant No	12	2.5370	0.2114	0.61	0.830
Residual	142	49.1389	0.3460		
Total	215	1703.6250			
Grand Mean		14.542			
CV		4.0			

Appendix 17: ANOVA Table for Grain Yield Kgs per ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replicate stratum	2	184815.	92407.	1.42	
Treatment	2	51844051.	25922025.	398.54	<.001
Variety	2	2425162.	1212581.	18.64	<.001
Trial	1	3345.	3345.	0.05	0.822
Treatment*Variety	4	223727.	55932.	0.86	0.498
Treatment*Trial	2	75995.	37998.	0.58	0.563
Variety*Trial	2	217523.	108762.	1.67	0.203
Treatment*Variety*Trial	4	118866.	29716.	0.46	0.767
Residual	34	2211435.	65042.		
Total	53	57304919.			
Grand Mean		3531			
CV (%)		7.2			