

**SOIL CHEMICAL PROPERTIES AND SUNFLOWER (*Helianthus annuus* L)  
PRODUCTIVITY RESPONSES TO SUNN HEMP INTERCROPPING  
AND MINERAL FERTILIZER APPLICATION IN  
DODOMA, TANZANIA**

**By**

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the Award of Master of Science Degree in Integrated Soil Fertility  
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Environmental Sciences, Kenyatta University**

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## DECLARATION

This thesis is my original work and has neither been presented for a degree award in any other University nor submitted elsewhere for any other award.

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## **DEDICATION**

This work is dedicated to my devoted parents, Mr. Raphael Chappa and Neva Ndabalo Atufigwege, as well as to my sisters Ester, Matilda, and Vaileth Raphael Chappa, brothers Clement and Zakaria Raphael Chappa, and fiancé, Mr. Oclever Green Yuda Mwakiposa, who looked after me while I was studying abroad and provided numerous prayers. I beseech God to grant you a long and fruitful life.

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## ACRONYMS AND ABBREVIATIONS

ANOVA	: Analysis of Variance
BNF	: Biological Nitrogen Fixation
CIAT	: International Centre for Tropical Agriculture
FAO	: Food and Agricultural Organization
FAOSTAT	: Food and Agricultural Organisation Statistics
ha	: Hectare
kg ha <sup>-1</sup>	: Kilogram per hectare
kg N ha <sup>-1</sup>	: Kilograms of nitrogen per hectare
LSD	: Least Significant Difference
N	: Nitrogen
NRCS	: Natural Resources Conservation Service
OC	: Organic Carbon
RCBD	: Randomised Complete Block Design
SSA	: Sub-Saharan Africa
t ha <sup>-1</sup>	: tonne per hectare
TMA	: Tanzania Meteorological Agency
URT	: United Republic of Tanzania
US\$	: United States Dollar
USDA	: United States Department of Agriculture

## TABLE OF CONTENTS

DECLARATION.....	ii
DEDICATION.....	iii
ACKNOWLEDGEMENT.....	iv
ACRONYMS AND ABBREVIATIONS.....	v
LIST OF TABLES.....	viii
LIST OF FIGURES.....	ix
ABSTRACT.....	x
CHAPTER ONE.....	1
INTRODUCTION.....	1
1.1 Background Information.....	1
1.2 Problem Statement.....	3
1.3 Justification.....	3
1.4 General Objective.....	4
1.4.1 Specific objectives.....	4
1.4.2 Hypothesis.....	4
1.5 Conceptual Framework.....	5
1.6. Significance of the Study.....	6
CHAPTER TWO.....	8
LITERATURE REVIEW.....	8
2.1 General Information about Sunflower Production.....	8
2.1 Economic Importance of Sunflower.....	9
2.3 Major Constraints to Sunflower Production in Tanzania.....	10
2.4 General Information about Sunn hemp Production.....	10
2.5 Importance of Sunn Hemp.....	11
2.6 Role of Nitrogen in Sunflower Crop.....	12
2.7 Importance of Intercropping Sunflower with Legume Crops.....	13
CHAPTER THREE.....	15
MATERIALS AND METHODS.....	15
3.1 Study Site.....	15
3.2 Treatments and Experimental Design.....	15
3.3 Crop Establishment and Agronomic Practices.....	17
3.4 Data Collection.....	18
3.4.1 Soil sampling and analysis.....	18

3.4.2 Plant sampling and field measurements .....	18
3.4.3 Sunflower yield and economic returns .....	19
3.5 Data Analysis .....	19
CHAPTER FOUR .....	20
RESULTS .....	20
4.1 Rainfall and Temperature Patterns During the Experimental Period .....	20
4.2 Initial Soil Chemical Properties for the Experimental Sites .....	20
4.2 Initial Soil Chemical Properties for the Experimental Sites .....	21
4.3 Effects of Intercropping Sunflower with Sunn Hemp Coupled with the Application of Mineral N Fertilizer on Soil Chemical Properties .....	23
4.4 Effects of Sunflower-Sunn Hemp Intercropping Coupled with Mineral Nitrogen Fertilizer on Sunflower Growth and Yield Parameters .....	26
4.4.1 Effects on sunflower growth parameters .....	26
4.4.2 Effects on sunflower yield parameters .....	33
4.5 Effects of Sunflower-Sunn Hemp Intercropping Coupled with Mineral Nitrogen Fertilizer on Economic Returns .....	36
4.6. Relationship Among the Assessed Variables: Sunflower Growth, Yield, and Economic Parameters .....	39
CHAPTER FIVE .....	41
DISCUSSION .....	41
5.1 Effects of Sunflower-Sunn Hemp Intercropping Coupled with the Application of Mineral Nitrogen Fertilizer on Soil Chemical Properties .....	41
5.2 Effects of Sunflower-Sunn Hemp Intercropping Coupled with Mineral Nitrogen Fertilizer on Sunflower Growth and Yield Parameters .....	43
5.3 Effects of Sunflower-Sunn Hemp Intercropping Coupled with Mineral Nitrogen Fertilizer on Economic Returns .....	46
5.4 Relationship Among the Assessed Variables .....	47
CHAPTER SIX .....	49
CONCLUSIONS AND RECOMMENDATIONS .....	49
6.1 Conclusions .....	49
6.2 Recommendations .....	49
REFERENCES .....	50
APPENDICES .....	65
Appendix I: Approval of Research Proposal .....	65

## LIST OF TABLES

Table 3.1: Treatments and their description .....	17
Table 4.1: Soil chemical properties for Kongwa and Bahi sites (at 0–0.3 m depth) before the establishment of the experiment in November 2021.....	22
Table 4.2: Soil chemical properties for Kongwa and Bahi sites (at 0–0.3 m depth) at the end of the experiment in April 2022 .....	25
Table 4.3: Sunflower yield parameters as influenced by mineral nitrogen fertilizer under different Sunflower-Sunn hemp planting patterns at Kongwa and Bahi sites in the 2021/2022 crop growing season.....	35
Table 4.4: Variable cost for different treatments at Kongwa and Bahi sites in the 2021/2022 crop growing season.....	37
Table 4.5: Gross income, net income, and benefit-cost ratio as influenced by mineral nitrogen fertilizer under different Sunflower-Sunn hemp planting patterns at Kongwa and Bahi sites in the 2021/2022 crop growing season.....	38
Table 4.6: Correlations (Pearson) among the growth (plant height, leaf area, no of leaves plant <sup>-1</sup> , head diameter, and nitrogen uptake), yield (No. of seeds plant <sup>-1</sup> , the weight of seeds plant <sup>-1</sup> , achene yield, and stover yield), and economic (gross income and net income) parameters .....	40

## LIST OF FIGURES

Figure 1.1: Conceptual framework showing the interaction of dependent, independent, and intervening variables.....	6
Figure 4.1: Rainfall and temperature patterns during the experimental period.....	21
Figure 4.2: Sunflower plant height at Kongwa and Bahi during the 2021/2022 crop growing season as influenced by mineral nitrogen fertilizer under different sunflower-Sunn hemp planting patterns.....	27
Figure 4.3: Sunflower leaf area at Kongwa and Bahi during the 2021/2022 crop growing season as influenced by mineral nitrogen fertilizer under different sunflower-Sunn hemp planting patterns.....	29
Figure 4.4: Number of leaves per sunflower plant at Kongwa and Bahi during the 2021/2022 crop growing season as influenced by mineral nitrogen fertilizer under different Sunflower-Sunn hemp planting patterns. ....	31
Figure 4.5 sunflower head diameter in Kongwa and Bahi sites during the 2021/2022 crop growing season as affected by mineral N fertilizer under different sunflower-Sunn hemp planting patterns.....	32
Figure 4.6: Sunflower nitrogen uptake in Kongwa and Bahi sites during the 2021/2022 crop growing season as influenced by mineral N fertilizer under different sunflower-Sunn hemp planting patterns.....	33

## ABSTRACT

Sunflower (*Helianthus annuus* L.) is one of Tanzania's high-potential cash crops. Nonetheless, nutrient depletion, especially nitrogen (N), is limiting its productivity. An integrated soil fertility management technique that entails intercropping sunflower with a leguminous plant like Sunn hemp (*Crotalaria juncea*) and the application of mineral N fertilizer can boost N availability for crop uptake hence resulting in high crop productivity. The study was conducted in the semi-arid -Dodoma region in Tanzania where it adopted a randomized complete block design (RCBD) with six treatments each replicated four times. These treatments were T1; Control (sunflower pure stand) without mineral nitrogen (N) fertilizer, T2; Sunflower-Sunn hemp intercrop under 1:1 row ratio without fertilizer, T3; Sunflower-Sunn hemp intercrop under 1:1 row ratio with fertilizer, T4; Sunflower-Sunn hemp intercrop under 2:1 row ratio without fertilizer, T5; Sunflower-Sunn hemp intercrop under 2:1 row ratio with fertilizer and T6; Sunflower pure stand with fertilizer. Data that were collected are soil chemical properties (soil pH, organic carbon, total nitrogen, available phosphorus, potassium, calcium, magnesium, and sodium), sunflower growth and yield parameters (plant height, leaf area, number of leaves per plant, sunflower head diameter, N uptake by sunflower leaves, achene yield, number of seeds per plant, weight of seed per plant, and stover yield), economic returns (gross income, net income, and benefit-cost ratio-BCR). The data from this study were tabulated in excel and then subjected to analyses of variance. The means of treatments that were significant were distinguished by using the least significant difference (LSD) at a 95% confidence interval. The results indicated that except for soil pH, the other chemical soil properties tended to increase significantly ( $p \leq 0.05$ ) under all the treatments containing integrated approaches like Sunn hemp and N fertilizer application relative to the sunflower pure stand treatment across the sites. Regardless of the site, T6 and T3 showed the best performance based on the sunflower growth and yield. For instance, at Kongwa the sunflower leaf area was highest in T3 (285 cm<sup>2</sup>) and T6 (282 cm<sup>2</sup>) with T4 having the least value of 149 cm<sup>2</sup>. A similar trend was observed for the number of Sunflower seeds per plant, the weight of sunflower seeds per plant, Sunflower achene yield, and Sunflower stover yields with the best-performing treatments being T6 and T3. T5 and T2 had the highest (US\$ 278 ha<sup>-1</sup>) and the lowest (US\$ 205 ha<sup>-1</sup>) cost of production. Economically, Kongwa outperformed Bahi. Specifically, based on treatments, T3 had the highest gross income both at Kongwa (US\$ 3412 ha<sup>-1</sup>) and Bahi (US\$ 1756 ha<sup>-1</sup>). This translated into respective net income and BCR of US\$ 1639 and 698, and 7.50 and 3.20. This study's findings will help rural poor farmers achieve better economic returns, hence reducing poverty.

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background Information

Sunflower, which is botanically referred to as *Helianthus annuus* (L.) was introduced in Tanzania from Europe and America during the colonial era as one of the cash crops (Njiku, 2019). The country is ranked tenth worldwide and second in Africa among the major producers of sunflower seeds (FAOSTAT, 2015). In this country, the crop is produced in fifteen regions, among them being Singida, Iringa, Dodoma, Manyara, and Rukwa (URT, 2012). Sunflower is one of the main oil vegetable crops with high value worldwide whereby in 2015 it had a production of 39.62 million tons (FAOSTAT, 2015). This crop is very important and is mainly grown by poor smallholder farmers as one of the means of increasing employment (Njiku, 2019). The crop is regarded as a major contributor to the improved livelihood of the smallholder farmers residing in the central corridor regions of Tanzania (Salisali, 2012). Nonetheless, the farmers still experience low production, making it impossible to meet the international market demand (Njiku, 2019).

The decline in soil fertility status is the biggest problem in dryland areas of sub-Saharan Africa whereby it affects the production of crops including oilseed crops like the sunflower (Babec *et al.*, 2020; Otieno *et al.*, 2021; Alkharabsheh *et al.*, 2021; Ochieng *et al.*, 2021). Most of the crops grown in dryland areas are produced under a low amount of nutrients like nitrogen and phosphorus leading to low yields (Swamila *et al.*, 2022; Seleiman *et al.*, 2021). Although there is constant upgrading of genetically improved varieties, currently those sunflower-producing countries have continued to experience low yields of between 1.1 and 2.4 t ha<sup>-1</sup>.

Dodoma is dominated by shallow soils originating from granite rocks and is generally referred to as Lithosol. All soils of Dodoma are of poor nutrient status and have a low amount of organic matter content, courtesy of the granitic parent materials, and low vegetation cover (Msanya *et al.*, 2018). Most of the smallholder farmers in most parts of Tanzania including Dodoma do not apply inorganic fertilizers or any other technology to replenish the nutrients (Budotela, 1995). In that case, the nutrient status of the soil where sunflower is grown is generally poor. Because in dryland there is poor nutrient availability, various approaches must be adopted to replenish the nutrients.

Integrated soil fertility management (ISFM) is crucial in enhancing soil properties and sunflower yield (Nungula *et al.*, 2023). For instance, a comprehensive review by Thapa *et al.* (2022) highlighted that ISFM practices have improved soil fertility status and increased sunflower productivity. The integration of nutrient management practices, such as organic and inorganic fertilizers, contributes to better soil nutrient content and availability, which is essential for sunflower growth (Thapa *et al.*, 2022). Moreover, ISFM focuses on maintaining soil health while reducing negative impacts on the environment (Mukherjee *et al.*, 2019; Kisaka *et al.*, 2023; Mugwe *et al.*, 2020). Such improvements in soil properties are conducive to sunflower root development, thus increasing crop yield (Thapa *et al.*, 2022). Furthermore, Ramesh *et al.* (2017) reported, that ISFM approaches can contribute to sustainable sunflower production. Recent studies, as seen in the works of Dambale *et al.* (2018) and Thapa *et al.* (2022), emphasize that ISFM practices not only lead to increased sunflower yields but also have the potential to suppress soil-borne diseases that can negatively affect sunflower crops. The combined effect of enhanced soil properties and improved nutrient management has demonstrated its significance in achieving higher sunflower productivity (Dambale *et al.* (2018).

Additionally, one of the approaches to replenishing the nutrients in the soil is through the process of growing many crop species in a single field, a technique called intercropping (Babec *et al.*, 2020; Maitra *et al.*, 2021; Gitari *et al.*, 2018a). The intercropping technique increases biodiversity in the field and increases the interactions between biotic components and abiotic factors (Maitra *et al.*, 2023). Bokan *et al.* (2016) and (Šeremešić *et al.* (2018) demonstrated that there are great benefits of intercropping in the sense of increasing yields per area, reducing the use of pesticides, and better utilization of available resources. Babec *et al.* (2020) and Nasar *et al.* (2022a, 2023) reported that intercropping crops with legumes can bring advantageous results on yield, also on other plant growth parameters at the same time while minimizing the cost of pesticides and nitrogenous fertilizer application, hence increasing profitability. Despite the numerous merits associated with intercropping, there is no documented work related to sunflower intercropping with Sunn hemp, which was the focus of the current study. Intercropping sunflower and Sunn hemp increases sunflower yields since Sunn hemp can fix a huge amount of nitrogen of up to 167 kg of nitrogen per hectare through its symbiotic association with Rhizobium bacteria.

## **1.2 Problem Statement**

Some of the contributors to poor sunflower yields in smallholder farmers are poor agronomic practices, lack of good infrastructures, degeneration in soil fertility, and low adoption of appropriate agricultural technologies (Otieno *et al.*, 2023; Babec *et al.*, 2020; Chappa *et al.*, 2022; Nungula *et al.*, 2023). The decline in soil fertility status in sub-Saharan Africa (SSA) is one of the key problems upsetting crop production (Mugo *et al.*, 2021; Mwadalu *et al.*, 2022; Mwakidoshi *et al.*, 2023). Particularly in East Africa, nitrogen and phosphorus have been noted as the most limiting macronutrients in agricultural crop production (Kyomuhendo *et al.*, 2018; Shao *et al.*, 2023; Mugo *et al.*, 2021).

Nitrogen is one of the restrictive nutrients to crop growth, and it can be depleted in the soil through various processes such as soil erosion, harvested biomass, denitrification process, and ammonia (NH<sub>3</sub>) volatilization in the soils with high pH after surface application of granular urea (Loomis and Connor 1992; Alhammad *et al.*, 2023a; Nyawade *et al.*, 2019a, 2020b). Leaching also occurs when nitrates pull out of the soil through drainage water (Nyawade *et al.*, 2019a; Arregui and Quemada 2006). Nitrogen (N) can be gained in various ways, which include natural mineralization, fertilizer addition, and biological fixation (Nyawade *et al.*, 2020a; Nasar *et al.*, 2022a). Increased N input influences growth rates, photosynthetic rates, and general plant productivity (Bai *et al.*, 2010; Nasar *et al.*, 2021).

The addition of N-containing fertilizers increases the level of N in the soil. In addition, using leguminous plants such as Sunn hemp can increase nitrogen. Of essence is the integrated soil fertility management approaches like using intercropping technology and fertilizers at the same time, which can increase nitrogen availability for the companion crops. Despite the potential of Sunn hemp as a nitrogen-fixing plant, there are inadequate studies on the effects of Sunn hemp in nitrogen fixation in the Sunn hemp-sunflower intercropping system.

## **1.3 Justification**

Poor soil fecundity status is one of the problems causing poor crop production in east Africa including sunflower. The nutrient depletion rate in the soils of SSA is as follows 41 kg of nitrogen (N), 31 kg of potassium (K), and 4 kg of phosphorus (P) per hectare (Mugo *et al.* 2021; Bekunda *et al.*, 2005). In that case, future development in the agriculture sector in SSA will largely hinge on well-managed land. Among the plant's nutrients, the most significant is nitrogen, and it has

been reported to be scanty in the soils of SSA (Midega *et al.*, 2015). Therefore, this is one of the reasons for the poor production of many crops in sub-Saharan Africa.

To increase net incomes per unit area of sunflower, farmers are required to adopt different technologies such as the addition of appropriate nutrients, and intercropping with legumes such as Sunn hemp, bean, pigeon pea, and others which enhances biological nitrogen fixation (BNF). Nutrient addition through the use of fertilizers increases nitrogen content in the soil (Ochieng' *et al.*, 2021; Sairaam *et al.*, 2023). Nevertheless, combining mineral fertilizers like urea which is the key source of nitrogen, with other practices such as intercropping with legumes results in even greater increases in nitrogen stock in the soil (Ochieng' *et al.*, 2021). In Hawaii, it was reported that Sunn hemp added about 160 kg of N per ha after 60 days of its growth (Rotar and Joy, 1983) whereas, in Alabama, Mansoer *et al.* (1997) reported a mean of 143 kg of N ha<sup>-1</sup> in 70 days. Thus, this shows that with such a large amount of N being produced, a crop like a sunflower ought to follow Sunn hemp to exploit the symbiotically fixed N. The study that was conducted by Mansoer *et al.* (1997), showed that 38% of the N in biomass remained available for maize planted 112 days after the Sunn hemp was slashed. This proves that Sunn hemp is good even for crop rotation practice.

#### **1.4 General Objective**

To contribute to the general soil fertility management and improved economic status of smallholder sunflower farmers using Sunn hemp and mineral nitrogen fertilizer.

##### ***1.4.1 Specific objectives***

- i. To determine the effect of Sunflower-Sunn hemp intercropping coupled with the application of mineral nitrogen fertilizer on soil chemical properties.
- ii. To examine the influence of Sunflower-Sunn hemp intercropping coupled with mineral nitrogen fertilizer on sunflower growth and yield parameters.
- iii. To assess the economic returns associated with Sunflower-Sunn hemp intercropping coupled with mineral nitrogen fertilizer.

##### ***1.4.2 Hypothesis***

- i. Chemical soil properties improve significantly under Sunflower-Sunn hemp intercropping systems combined with the application of mineral nitrogen fertilizer.
- ii. The growth and yield of Sunflower are influenced significantly when the crop is intercropped with Sunn hemp coupled with the application of mineral N fertilizer.

- iii. The profitability of Sunflower increases significantly under intercropping with Sunn hemp coupled with the application of mineral N fertilizer.

### **1.5 Conceptual Framework**

The major parameters of the experiment were: The independent variables/problem namely low sunflower yields and economic returns, low soil nutrient status caused by poor soil fertility, and low N-nutrient uptake (Fig. 1.1). Dependent variables (output) were improved sunflower crop yields and profitability, improved sunflower growth parameters, increased nitrogen uptake, as well as improved soil chemical properties such as soil pH, total nitrogen, organic carbon, available phosphorus, and exchangeable bases (Ca, Mg, K, Na). By intercropping sunflower with the nitrogen-fixing plant (Sunn hemp), coupled with the application of mineral N (urea) fertilizer, the study anticipated that the aforementioned challenges would be addressed.

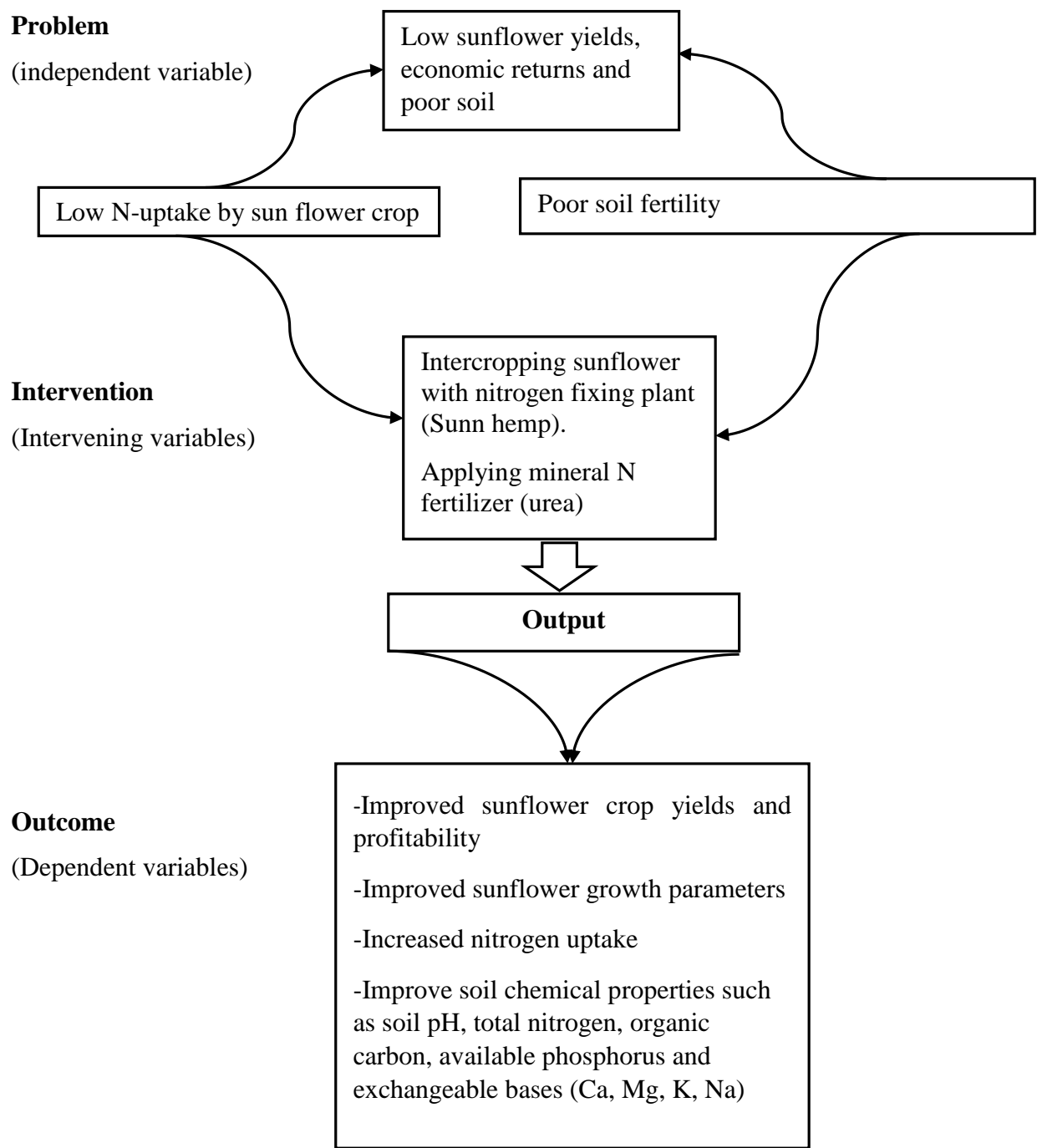


Figure 1.1: Conceptual framework showing the interaction of dependent, independent, and intervening variables (Source, Author).

### 1.6. Significance of the Study

The current study sought to promote sunflower production, economic returns, and improve soil fertility using Sunn hemp legume, nitrogenous fertilizer, and the integrated approach which is the combination of Sunn legume and nitrogenous fertilizer (urea). It intended to find out the most

optimum and efficient approach that could lead to not only improved sunflower yield and profitability but also increased nitrogen uptake, coupled with improved soil chemical properties such as soil pH, total nitrogen, organic carbon, available phosphorus, and exchangeable bases (Ca, Mg, K, Na). Therefore, the study would offer insight to sunflower farmers on the most suitable approach to adopt, for the improvement of soil chemical properties with maximum sunflower yields and eventually optimal economic returns.

Researchers and other agricultural stakeholders like extension agents, farmers, and others will get useful information on the benefits of intercropping sunflower with Sunn hemp, as well as using integrated approaches. The farmers would also be able to conserve the environment as well as restore the soil fertility, by embracing the biological means of crop production using Sunn hemp legume to fix nitrogen hence optimizing final sunflower yield and increasing economic returns. The results from this study will guide policymakers in developing appropriate agricultural policies such as on how to reduce the cost of farming, particularly for smallholder farmers by using Sunn hemp legume.

## CHAPTER TWO

### LITERATURE REVIEW

#### **2.1 General Information about Sunflower Production**

Sunflower, which is botanically referred to as *Helianthus annuus* is an annual crop characterized by a large inflorescence flowering head. It's called a sunflower because the shape of its head takes the shape of the sun (Scherr and McNeely, 2008). Sunflower is characterized by an irregular stem that is hairy with coarsely notched leaves, with a circular head that has approximately 1000 to 2000 flowers connected by only one receptacle base (Malézieux *et al.*, 2009). Based on the variety, sunflower can grow up to the height of 4.5 m with a head measuring up to 30 cm in diameter (Muok *et al.*, 2010).

Even though sunflower is grown on every continent, the largest producers of the crop include Argentina, Eastern Europe, the European Union, the United States of America (USA), India, and China. Between the years 1997 and 2002, the USA accounted for about 10% of global sunflower production (Oil *et al.*, 2014). Between the years 1997 and 2004, sunflowers ranked fifth behind soybeans, rapeseed, cottonseed, and peanuts. In 2015, global sunflower production was roughly 40 million metric tons (FAOSTAT, 2015).

Like palm oil and groundnuts, sunflower is taken as one of the potential substitute sources of the oldfangled vegetable oil in the tropics (Ogunremi, 2000). Tanzania is rated at position 10 worldwide among the major producers of sunflower seeds and second in Africa (Salisali, 2012; FAOSTAT, 2015). In Tanzania, sunflower is produced in fifteen regions, among them being Singida, Iringa, Dodoma, Manyara, and Rukwa with capacities of 40, 13.83, 12.35, 11.91, and 11.18% respectively (URT, 2012). Sunflower is the crop that improves the livelihood of the smallholder farmers residing in the central corridor regions of Tanzania (Salisali, 2012).

Sunflower is considered to be one of the drought-tolerant crops because of its deep extensive taproot system which can extend beneath the normal rooting depth of most annual crops to extract water and nutrients (Acland, 1971; Chappa *et al.*, 2022). García-Vila and Fereres, 2012) showed that sunflower is cultivated under both arid and semiarid climatic conditions where it can be under irrigation or rainfed. When under irrigation, sprinkler and furrow irrigation methods are the most preferred and common irrigation practices for the crop. It is worth noting that this crop requires only a limited amount of water (~ 50 mm) as supplemental irrigation (Casadebaig *et al.*, 2011).

In sunflower production, there are different cropping systems, which can take both relay, row, and strip intercropping systems (Robinson, 1984). When compared with sole crops, intercropping sunflowers with legumes is often regarded to be of high importance because it increases land productivity. For instance, intercropping sunflower with soybeans was shown to improve the productivity of the soil, and that phenomenon was attributed to the complementary use of resources among the two companion species (Andrade *et al.*, 2012; Echarte *et al.*, 2011).

## **2.1 Economic Importance of Sunflower**

Sunflower is one of the vegetable oils crops, with many benefits, such as being a source of nutritional food for humans and having its seed cake involved in animal feed preparations as an ingredient (Malik *et al.*, 2017). Of essence to note is that after processing, 36% by the weight of the sunflower cake and the meal is mainly sunflower with about 45-50% protein content (Oliveira *et al.*, 2016; Malik *et al.*, 2017). Sunflower meal is comprised of minerals, vitamin B, and amino acids, besides being characterized by a high antioxidant content, which is captivating nutritious food meant for humans and the ingredients for animal feeds like chicken, and pigs (Wanjari and Waghmare, 2015).

As one of the promising protein sources, in food preparation, sunflower seeds can be prepared as a substitute for soybeans whose production is limited (Oliveira *et al.*, 2016). Its seeds can be processed into various forms like flour, roasted, baked, or boiled as a composite functional meal (Wanjari and Waghmare, 2015; Grasso *et al.*, 2019). The oil obtained from sunflower seeds is consumed by many households for cooking. In addition, it is a raw material in food industries for making butter, snacks, margarine, and bread (Kottapalli *et al.*, 2020).

Several parts of sunflowers have been diagnosed to be competent in traditional medications in the treatment of various health problems such as sores, dysentery, diarrhoea, cough, and skin rashes (Mohiuddin, 2019). Processed sunflower seeds contain dietary fiber, fatty acids, high protein, vitamins, and minerals and it's a source of antioxidants with low carbohydrates (Shahbaz *et al.*, 2018). The nutritive components of sunflower oils determine their functional characteristics and they are also active in avoiding human illnesses like coronary heart disease, cancer, hypercholesterolemia, hypertension, and diabetes (Katsarou *et al.*, 2015).

Sunflower is not only involved in the production of edible vegetable oil, but also it is a source of raw materials in the production of many products such as biodiesels, cosmetics, lubricants, paints, as well as drugs (Rocha-Filho *et al.*, 2016). In addition, Muok *et al.* (2010) reported that

sunflower oil is useful in making varnishes and paints since its oil has a better drying feature which does not pose any effect on the colour of the polished surface.

### **2.3 Major Constraints to Sunflower Production in Tanzania**

Sunflower production is being hindered by many factors, which can be biotic or abiotic. In general, challenges encountered in the production of sunflower includes decreased soil fertility, lack of improved sunflower seed varieties, unpredictable rainfall, low rainfall, undependable markets, price fluctuations, and the high price of agricultural inputs (such as fertilizers, chemicals, and machinery). Others are pests, and disease attacks, poor agricultural extension services, lack of awareness, absence of farm machinery, attacks by birds, competition from edible oil imports, and extreme weather events (Adeleke and Babalola, 2020).

During the cultivation period of sunflower, various diseases such as leaf spots, rusts, stem rots, head rots, root rots, and white blisters can emerge. Nevertheless, these can be eliminated easily using different farm practices such as crop rotation, using biopesticides, and irrigation methods (Ebrahimian *et al.*, 2019). Climate change has caused great effects on many crops including sunflower with a great impact on production and yields (Majeed *et al.*, 2023). That is, due to inadequate rainfall, the water supply to the crops is limited which ultimately results in low yields (Ochieng' *et al.*, 2023).

Lack of knowledge and information involving sunflower cultivation, processing, and marketing creates many difficulties for farmers. More and adequate information about planting, seed rate, the type and quantity of fertilizers to be applied, disease and pest control, and marketing availability is vital to attaining optimal yield in sunflower farming (Gupta, 2014). Birds', insects', and rodents' attacks might lead to a vast loss of the sunflower yield in the field. Human beings can also cause the loss of sunflower outputs by plucking the flowers due to their captivating and beautiful look, finally resulting in both quantity and quality yield loss (Adeleke and Babalola, 2020).

### **2.4 General Information about Sunn hemp Production**

Sunn hemp, which is botanically referred to as *Crotalaria juncea*, L, is one of the tropical legumes that originated from India about 400 B.C. It was first introduced in Europe in the years 1791 and 1792. The largest producers of Sunn hemp in the world include China, India, Bangladesh, and Brazil. It's also produced in other countries like Romania, the United States, Russia, Commonwealth of Independent States (CIS) countries, Korea, and Pakistan (Chaudhury

*et al.*, 1997). Cook and White (1996) reported that the first research in the United States involving Sunn hemp was done in the 1930s. At that time the crop was introduced to be used mainly as a green manure crop or warm-season cover crop (Mansoer *et al.*, 1997).

Sunn hemp has long taproots with lobbed nodules and a stem that is almost 2 cm in diameter. It's characterized by an open raceme inflorescence, with its flowers containing five hairy sepals and deep yellow petals. The crop matures between 60 and 90 days after planting producing small flattened, dark grey to black seeds. Through its association with rhizobium bacteria, Sunn hemp can fix nitrogen and can transfer the residual potash and phosphorus from the deeper soil layers to the upper horizons. Within sixty days it can grow up to the height of 6 feet, producing a lot of organic matter of up to 4 tons per ha. the crop grows well in dry regions with well-drained sandy soils characterized by a pH of 5-8.2 (Carrie and Lauren, 2021). It adapts well to soils that range from coarse to fine-textured, and also to both infertile and fertile soils. Sunn hemp also adapts to variable amounts of rainfall.

## **2.5 Importance of Sunn Hemp**

Sunn hemp is normally utilized as green manure to improve the fertility of the soil because it can produce high amounts of biomass within a few days between 60 and 90 days by which the plant can reach a height of 4 to 6 feet (USDA, 1999). As a legume, Sunn hemp normally fixes a large amount of nitrogen hence making the soil more fertile. Rotar and Joy (1983) and Mansoer *et al.* (1997) reported that Sunn hemp added about 160 and 143 kg of N per ha, respectively after 60 to 70 days of its growth. Thus, this shows that with such a large amount of N being produced, a crop like a sunflower must follow Sunn hemp to exploit the symbiotically fixed N. The study that was conducted by Mansoer *et al.* (1997), showed that 38% of the N in biomass continued to be available for maize that was planted 16 weeks after mowing the Sunn hemp.

Sunn hemp gives a similar advantage to grass cover crops which consist of increasing organic carbon contents, improving water infiltration, erosion control, the addition of nitrogen by biological nitrogen fixation, and cooling soil temperatures (Reeves, 1994), The nitrogen provided by the Sunn hemp can decrease nitrogenous fertilizers requirements (Ebelhar *et al.*, 1984; Holderbaum *et al.*, 1990).

Ribas *et al.* (2003) reported that Sunn hemp intercropped with okra demonstrated higher productivity than the non-intercropped okra. The study conducted by De Oliveira *et al.* (2007) revealed that intercropping taro with Sun hemp increased the amount of nitrogen in the system,

whereby 211 kg ha<sup>-1</sup> of N was observed, correspondingly Sunn hemp endorsed the cycling of nutrients to an average of 17 kg ha<sup>-1</sup>, 85 kg ha<sup>-1</sup>, 151 kg ha<sup>-1</sup> and 27 kg ha<sup>-1</sup> of phosphorus, potassium, calcium, and magnesium, respectively. This tropic legume can produce huge amounts of biomass and symbiotic nitrogen in an eight to twelve weeks' frost-free period (NRCS, 1999). Compared with other cover crops which are temperate warm season like velvet bean (*Mucuna pruriens*) and cowpea, Sunn hemp (*Crotalaria juncea*) accumulates a high amount of phosphorus (P) and nitrogen because it produces a high amount of biomass (Wang *et al.*, 2011).

Sunn hemp can also serve as a cover crop preventing soil erosions, and improving soil properties besides conserving soil water and playing a key role in nutrient recycling. Rotar and Joy (1983), reported that Sunn hemp can equally be used as a forage crop, making paper fiber, as well as a substitute to fuel crops.

Generally, Indian hemp which is drought tolerant and adapts to a wide variety of soils has the following advantages, improves and modifies the soil condition, adds nitrogen to the soil, produces huge organic matter that is beneficial to the soil by resisting root-knot nematodes, and suppresses weeds. It is not an alternate host of diseases and pests that affect commercial crops (Rotar and Joy, 1983).

## **2.6 Role of Nitrogen in Sunflower Crop**

Nitrogen is one of the plant macronutrients that has many influences on sunflower growth parameters including the size of the leaves, the number of the leaves, the size, and weight of the seed, yield, and oil content (Olalde *et al.*, 2000; Bindra and Khararwa, 1992). It is the nutrient that is required at a high amount for the sunflower to produce optimally. The nutrient helps to increase the development and growth of the sunflower plant. Increasing the amount of nitrogen supplied to the crop also stimulates leaf expansion as well as increases the quantity of dry matter (Nasar *et al.*, 2022a). Bindra and Khararwa (1992) reported that increasing the nitrogen application rate to the sunflower crop leads to an increased content of oil in the seeds as well as a seed yield of up to 60 kg of sunflower seeds per hectare. Ayub *et al.* (1999) observed that the growth parameters of sunflowers which include, the stem diameter, leaf area and the number of leaves per plant, plant height, the weight of seed, and achene increased with an application of nitrogen at a rate of 100 kg N ha<sup>-1</sup> compared to a lower level of 50 kg N ha<sup>-1</sup>.

Olalde *et al.* (2000) in their field study reported that increased nitrogen levels also help in increasing the production of biomass, seed yields, the number of achenes per capitulum, and head

diameter, besides increasing nutrient and water use efficiency. Singh *et al.* (2000) observed that increasing nitrogen application leads to an increase in oil contents, head diameter, as well as the number of seeds. Iqbal *et al.* (2001) reported that some of the phenological sunflower parameters such as leaf area, the number of leaves per plant, head diameter, and height of the plant were maximized at the N level of 120 kg ha<sup>-1</sup>.

## **2.7 Importance of Intercropping Sunflower with Legume Crops**

Intercropping refers to the concurrent cultivation of at least two kinds of crops, grown in the area in which there is the optimal use of resources (water, nutrients, carbon dioxide, light, etc) throughout the season or part of their growing season (Raza *et al.*, 2021; Mwakidoshi *et al.*, 2023; Babec *et al.*, 2020; Gitari *et al.*, 2018b). As opposed to monocropping, which is normally practiced in large-scale agriculture, and involves heavy use of machines, smallholder farmers, prefer intercropping as they target to produce food to sustain their families. Intercropping practice is important since it produces stable yields, and only a few inputs for nutrient additions, pest, and disease control are required yet it has the ultimate goal of maintaining soil fertility (Maitra *et al.*, 2021; Faridvand *et al.*, 2021).

Gitari *et al.* (2018a, b, 2020a), Jena *et al.* (2022), and Nyawade *et al.* (2019a, b) have reported that legume intercropping is one of the climate-smart cropping strategies useful to small-scale farmers, with high climatic related risks diversification. In their studies, Nyawade *et al.* (2020b), and Nasar *et al.* (2022b) reported that intercropping legumes reduce soil nutrient demands besides enhancing ground cover establishment and increasing crop yields. Saady and Elmetwally (2009) reported that one of the tactics to increase the yields of field crops is intercropping. Intercropping is a component of sustainable agriculture in which the degree of biodiversity is high with resultant biological stability (Baumann *et al.*, 2001). Under intercropping, the companion crops use nutrients, water, and light more efficiently (Babec *et al.*, 2020; Zhang and Li, 2003; Gitari *et al.*, 2020b; Kisaka *et al.*, 2023). Cover crops under intercropping, improve not only the chemical properties but also the biological properties of the soil, with resultant high production of the subsequent crop (Panda *et al.*, 2020; Raza *et al.*, 2022). An intercropping system is good for weeds, diseases, pest suppression, and soil erosion control (Batista *et al.*, 2019; Alhammad *et al.*, 2023a; Nyawade *et al.* 2019a).

When intercropped with maize, Winter legumes (Sunn hemp) offer many benefits such as soil erosion control, enhanced water infiltration, increased organic C contents, as well as cool soil

temperatures (Reeves, 1994). Multi-cropping systems that involve legumes can lead to nitrogen fixation symbiotically and rise crop yield through better and more efficient use of the resource (Jena *et al.*, 2022; Sousa *et al.*, 2022). Most of the legumes increase organic matter quantities which support biological activity in the soil, rising the nutrient availability of the soil (Nyawade *et al.*, 2019c; Shao *et al.*, 2023; Mirriam *et al.*, 2022). High yields can be attained when crop species are intercropped than when the crops are cultivated under monoculture (Beckage and Gross, 2020). Nonetheless, from various literature and to the best of my understanding the intercropping between sunflowers and legumes is quite rare, hence the reason behind this study.

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 Study Site

The study was conducted in two districts: Bahi and Kongwa, which are based in the semi-arid region of Dodoma in Tanzania. The site in Kongwa is located at 36.43° E, 6.17° S, 1125 m above sea level whereas the one in Bahi is situated at 35.19° E, 5.57° S, 900 m above sea level (Fig. 3.1). Generally, Kongwa district receives a total annual rainfall ranging from 500 to 750 mm whereas the average rainfall for the Bahi district ranges between 530 and 640 mm. Rainfall distribution is mono-modal starting in late November, reaching a peak in December/January, and ending in April. The temperatures of the Dodoma region differ from season to season, with an average maximum and minimum of 29 and 17 °C, respectively. The sites are dominated by very shallow soils developed on granite rocks, classified as Lithosol. These soils are of little organic matter and low nutrient status, due to low vegetation cover and the granitic parent materials (Msanya *et al.*, 2018). In addition, they are dominated by deciduous trees (Baobab) as the main vegetation type with the agricultural farming systems being mixed cropping, monocropping, and livestock keeping.

#### 3.2 Treatments and Experimental Design

The study adopted a randomized complete block design (RCBD) with 24 plots each with a size of 5 m x 6 m (Fig. 3.2). There were six different treatments each replicated four times (Table 3.1). A 0.5 m path was used to separate the plots within blocks and the four blocks were set at 1 m apart. For the treatments that required fertilizer, urea fertilizer was applied to sunflowers only at planting and at the vegetative stage.

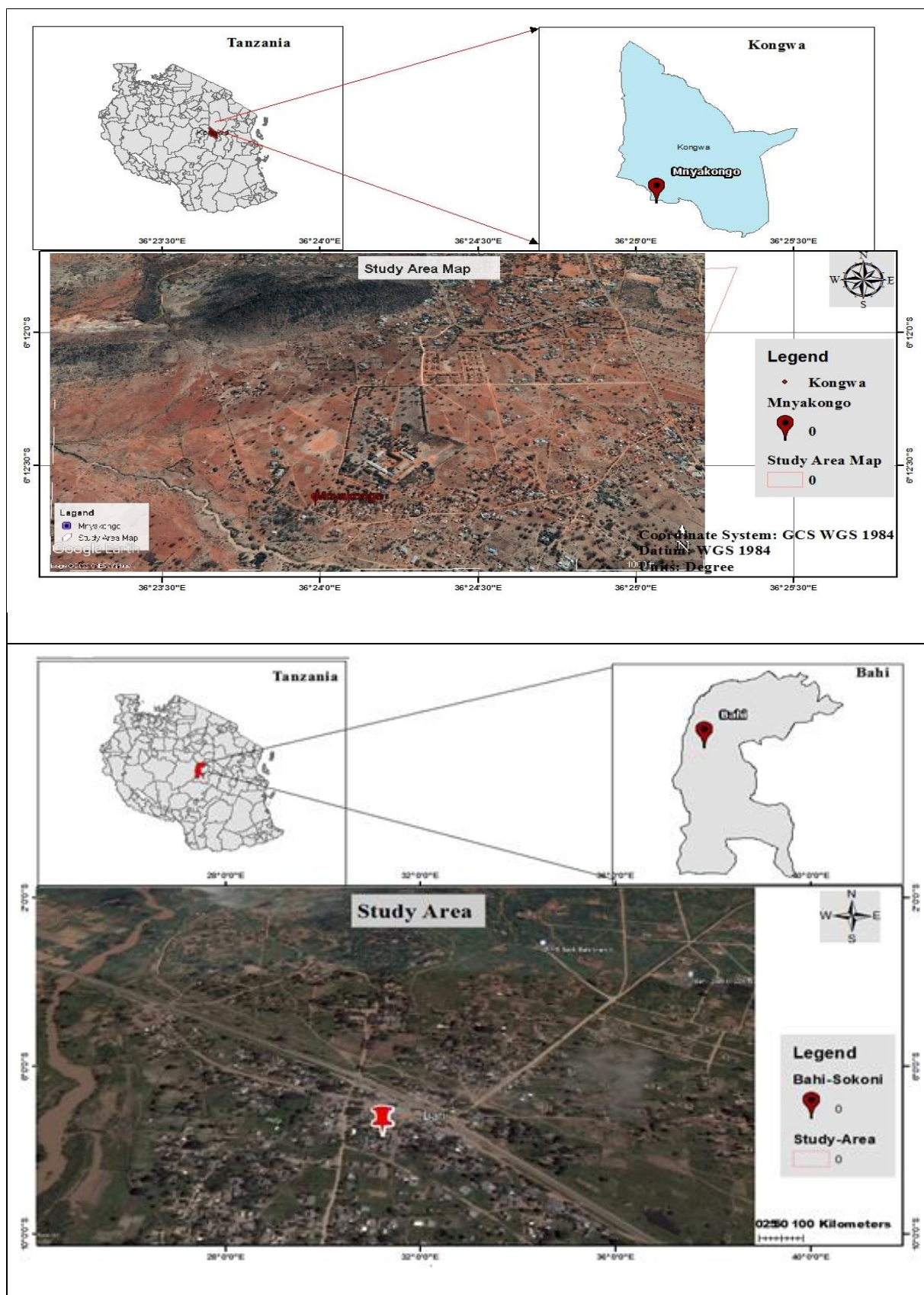


Figure 3.1: Map showing the study sites in Kongwa and Bahi districts (GIS-generated maps)



Figure 3.2: Layout of the experimental plots

Table 3.1: Treatments and their description

Treatment code	Treatment's descriptions
T1	Control (sunflower pure stand) without mineral nitrogen (N) fertilizer
T2	Intercrop (Sunflower + Sunn hemp) under a 1:1 row ratio without N fertilizer
T3	Intercrop (Sunflower + Sunn hemp) under a 1:1 row ratio with N fertilizer
T4	Intercrop (Sunflower + Sunn hemp) under a 2:1 row ratio without N fertilizer
T5	Intercrop (Sunflower + Sunn hemp) under a 2:1 row ratio with N fertilizer
T6	Sunflower pure stand with N fertilizer

### 3.3 Crop Establishment and Agronomic Practices

Before the onset of the rain, the land was cleared and well prepared by both ploughing and harrowing to make an appropriate tilth for the crops. Then sunflower was planted at an interplant spacing of 30 cm and inter-row spacing of 75 cm. For 1:1 and 2:1 sunflower-Sunn hemp intercropping, the inter-row spacing of Sunn hemp was 75 and 35 cm, respectively. Two sunflower seeds were planted per hill, whereas Sunn hemp seeds were broadcasted following a straight line (for the intercropped plots). The 100 Kg N ha<sup>-1</sup>, supplied by urea fertilizer was applied only to the sunflowers at a rate of 5 g of fertilizer per plant. Other routine management

practices such as weeding, pest control, thinning, and gapping were performed accordingly throughout the crop-growing period.

### **3.4 Data Collection**

#### ***3.4.1 Soil sampling and analysis***

The soil sampling was done twice (before and after planting experimental trials) to a depth of 30 cm with the aid of an auger, by considering a zig-zag random soil sampling technique. About 10-15 subsamples were obtained from each experimental site before establishing the experiment whereas, after crop harvest, the soil samples were taken separately from each of the 24 plots. Composite samples of roughly 500 g were then drawn after mixing the sub-samples in a plastic bucket. The samples were then delivered to the laboratory for chemical analysis and interpretation.

Soil pH was determined using a pH meter according to Ryan *et al.* (2001). Total nitrogen and organic carbon were analyzed using the Kjeldahl (Bremner, 1996) and the Walkey and black (Nelson and Sommers, 1996) methods respectively. The exchangeable bases which included Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, and Ca<sup>2+</sup> were analyzed using a flame spectrophotometer method (Kalra and Maynard, 1991). Available phosphorus was extracted using the Mehlich-3 (M-3) technique (Bolland *et al.*, 2003; Mehlich, 1984) and read in a spectrophotometer (Murphy and Riley, 1962).

#### ***3.4.2 Plant sampling and field measurements***

From a net area of 2 m<sup>2</sup> taken from the middle of each plot, three plants were selected to determine the growth parameters: leaf area, plant height, and the number of leaves per plant, and yield indices: number of seeds per capitulum of sunflower, head diameter, the weight of seeds per plant and achene yield per ha. Measurements of the aforementioned growth parameter were considered at three phenological stages: vegetative, tasselling, and harvesting. Head diameter and height were determined using a tape measure, whereby the height was measured from the ground of the sunflower plant to the head of the sunflower. The number of leaves from each sample plant was counted from the first to the last visible leaf of the plant.

Nitrogen uptake was measured by plucking two leaves next to the sunflower head. These leaves were chopped and mixed after which 500 g composite samples were drawn per plot and packed in khaki bags. The samples in khaki bags were placed in an oven to dry at 65 °C to a constant weight after which they were ground using a Wiley mill to be ready for analyses. By following

the micro-Kjeldahl procedures given by Yuen and Pollard (1953), the plant tissues were analyzed for total N concentration.

### ***3.4.3 Sunflower yield and economic returns***

At the harvesting stage, ten sunflower heads were taken randomly at the middle of each plot, sun-dried, and shelled manually. By use of an electronic weighing balance, the weight of the sunflower seeds was determined in kilograms then conversion into tonnes per hectare was made. For stover yield, sunflower leaves together with stalks were weight together.

The cumulative cost of production was determined by adding all costs used in the production of the crop, which consisted of the costs of seeds, fertilizers, pesticides, labour, and farm leasing costs (Table 4.5). The gross income was calculated based on the prevailing sunflower market price of US\$ 0.66 kg<sup>-1</sup>. Net income as well as a benefit: cost ratio were calculated using the two formulas given in Equations 1 and 2 (Cheptoek *et al.*, 2021).

$$\text{Net income} = \text{Gross income} - \text{Total cost of production} \quad (1)$$

$$\text{Benefit: Cost Ratio} = \frac{\text{Net income}}{\text{Total cost of production}} \quad (2)$$

### **3.5 Data Analysis**

The data from this study were tabulated in Excel and then subjected to ANOVA using the statistical software, GenStat (GenStat, 2010). The significant means were distinguished by using the least significant difference (LSD) at a 95% confidence interval. The relationship between soil parameters was determined by conducting a correlation analysis.

## CHAPTER FOUR

### RESULTS

#### 4.1 Rainfall and Temperature Patterns During the Experimental Period

At Kongwa, the highest (30.2 °C) maximum and minimum (19.1 °C) temperatures were noted with December 2021 having the lowest record for minimum (17.6 °C) temperature (Fig. 4.1). On the other hand, this site had January and February of 2022 receiving the highest amounts of rainfall of 314.1 mm and 299.4 mm, respectively.

Bahi was warmer and wetter than the Kongwa site with the highest maximum temperature of 31.8 °C in December 2021 and 30.3 °C in April 2022 whereas the highest minimum temperature was recorded in December (22.7 °C) and January (20.5 °C). January and February were distinguished to have received the highest amount of rainfall 352.6 and 447.3 mm, respectively compared to December 2021 which was the driest month with 49.1 mm.

#### 4.2 Initial Soil Chemical Properties for the Experimental Sites

Before the establishment of the experiment, the soil at the Kongwa site had total nitrogen of 0.4 g kg<sup>-1</sup>, organic carbon of 5.2 g kg<sup>-1</sup>, and available phosphorus of 62 mg kg<sup>-1</sup> with a neutral pH of 7.2 (Table 4.1). It was also found to contain 0.27, 1.65, 0.20, 0.23, and 0.03 cmol kg<sup>-1</sup> of potassium, calcium, magnesium, and sodium, respectively. On the other hand, the Bahi site was slightly acidic with a pH of 6.3, lower total nitrogen (0.4 g kg<sup>-1</sup>), and organic carbon (4 g kg<sup>-1</sup>) with available phosphorus of 12 mg kg<sup>-1</sup>. Nonetheless, besides having lower exchangeable potassium (0.13 cmol kg<sup>-1</sup>) and sodium (0.22 cmol kg<sup>-1</sup>) than the Kongwa site, Bahi exhibited higher exchangeable magnesium (2.22 cmol kg<sup>-1</sup>) and calcium (2.23 cmol kg<sup>-1</sup>).

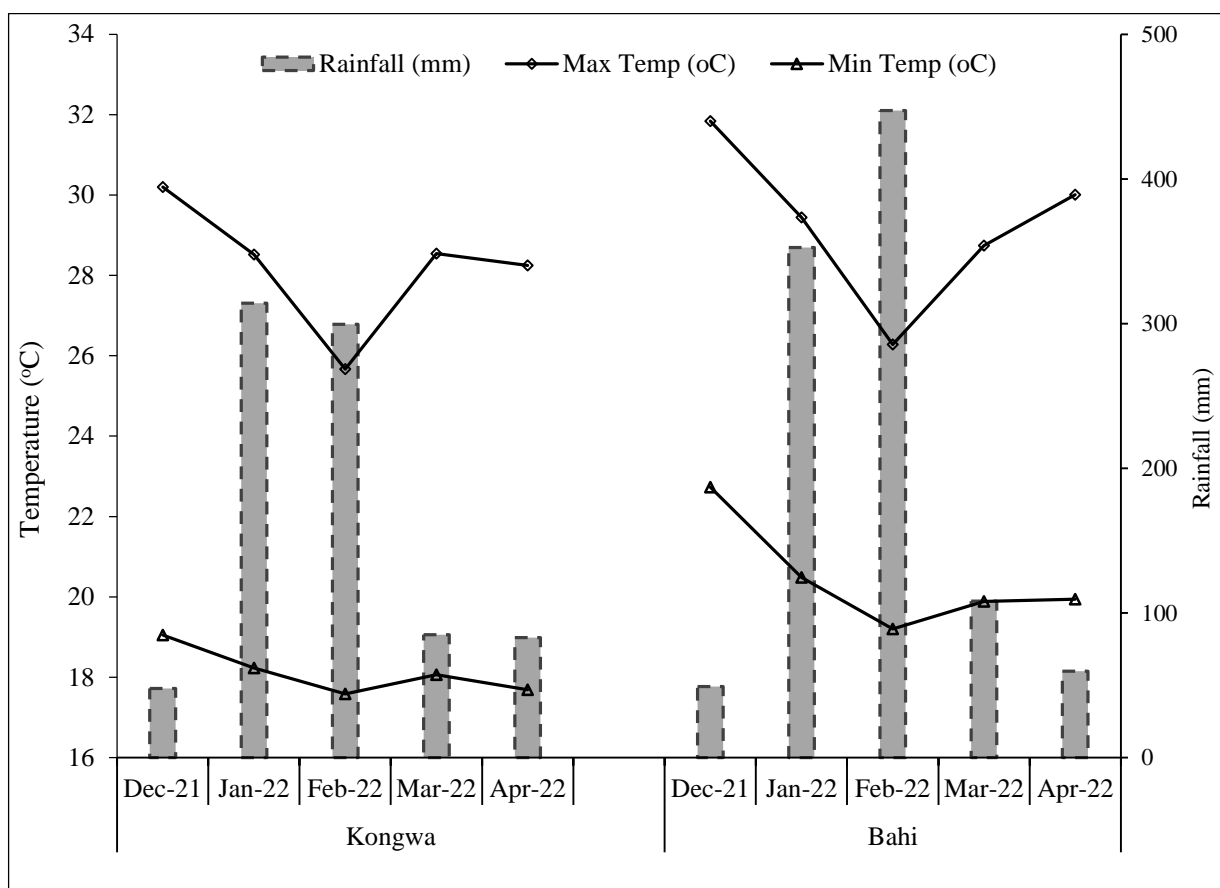


Figure 4.1: Rainfall and temperature patterns during the experimental period

#### 4.2 Initial Soil Chemical Properties for the Experimental Sites

Before the establishment of the experiment, the soil at the Kongwa site had total nitrogen of  $0.4 \text{ g kg}^{-1}$ , organic carbon of  $5.2 \text{ g kg}^{-1}$ , and available phosphorus of  $62 \text{ mg kg}^{-1}$  with a neutral pH of 7.2 (Table 4.1). It was also found to contain 0.27, 1.65, 0.20, 0.23, and  $0.03 \text{ cmol kg}^{-1}$  of potassium, calcium, magnesium, and sodium, respectively. On the other hand, the Bahi site was slightly acidic with a pH of 6.3, lower total nitrogen ( $0.4 \text{ g kg}^{-1}$ ), and organic carbon ( $4 \text{ g kg}^{-1}$ ) with available phosphorus of  $12 \text{ mg kg}^{-1}$ . Nonetheless, besides having lower exchangeable potassium ( $0.13 \text{ cmol kg}^{-1}$ ) and sodium ( $0.22 \text{ cmol kg}^{-1}$ ) than the Kongwa site, Bahi exhibited higher exchangeable magnesium ( $2.22 \text{ cmol kg}^{-1}$ ) and calcium ( $2.23 \text{ cmol kg}^{-1}$ ).

Table 4.1: Soil chemical properties for Kongwa and Bahi sites (at 0–0.3 m depth) before the establishment of the experiment in November 2021

Site	Block	pH	Carbon (g kg <sup>-1</sup> )	Nitrogen (g kg <sup>-1</sup> )	Phosphorus (mg kg <sup>-1</sup> )	Potassium (cmol kg <sup>-1</sup> )	Calcium (cmol kg <sup>-1</sup> )	Magnesium (cmol kg <sup>-1</sup> )	Sodium (cmol kg <sup>-1</sup> )
Kongwa	1	7.02	4.72	0.35	67.25	0.28	1.81	0.15	0.22
	2	7.14	4.21	0.52	55.15	0.25	1.42	0.23	0.24
	3	7.15	6.82	0.42	64.03	0.29	2.05	0.23	0.24
	4	7.17	5.20	0.43	62.21	0.27	1.44	0.18	0.22
Bahi	1	6.26	4.20	0.38	13.0	0.11	2.62	0.22	0.24
	2	6.38	3.80	0.38	12.2	0.13	2.82	0.25	0.22
	3	6.28	4.40	0.42	12.6	0.14	1.60	0.23	0.21
	4	6.12	3.60	0.33	10.2	0.14	1.94	0.21	0.22

### **4.3 Effects of Intercropping Sunflower with Sunn Hemp Coupled with the Application of Mineral N Fertilizer on Soil Chemical Properties**

Compared with the sunflower pure stand treatment, all the other treatments containing integrated approaches like Sunn hemp and N fertilizer application were found to have an increase in nutrient levels. The soil of the Kongwa site was observed to have a high percentage of nutrient increase (changes) compared to the Bahi site. For instance, at Kongwa, the soil pH dropped from 7.12 (Table 4.1) to 6.85, 6.92, and 6.90 (Table 4.2) in the treatments supplied with N fertilizers: T3, T5, and T6 respectively. The soil pH remained almost unchanged in the non-fertilized treatment. Similar results were obtained at the Bahi site where the soil pH dropped from 6.26 (Table 4.1) to 6.18, 6.17, and 6.17 (Table 4.2) in T3, T5, and T6, respectively.

With reference to the baseline value of  $5.2 \text{ g kg}^{-1}$  for organic carbon at the Kongwa site, there were increases of 8% in T2, 10% in T3, 3% in T4, and 2% in T5, and decreases of 3 and 4% in T6 and T1, respectively (Table 4.2). At the Bahi site, the organic carbon was higher by 0.2, 0.8, 0.9, 1.2, and  $0.2 \text{ g kg}^{-1}$  for T6, T2, T3, T4, and T5, respectively, compared to the amount of carbon before the establishment. At the Kongwa site, the total nitrogen values noted in T2 ( $2.1 \text{ g kg}^{-1}$ ), T3 ( $0.6 \text{ g kg}^{-1}$ ), T4 ( $0.5 \text{ g kg}^{-1}$ ), and T5 ( $0.5 \text{ g kg}^{-1}$ ) were higher by 1.7, 0.2, 0.1, and  $0.1 \text{ g kg}^{-1}$  relative to the control (T1) (Table 4.2). Similarly, at the Bahi site, the total nitrogen indicated a positive trajectory with increases of 0.3, 0.4, 0.5, 0.5, 0.5, and  $0.6 \text{ g kg}^{-1}$  in T1, T6, T3, T2, T5, and T4, respectively compared to the former value ( $0.4 \text{ g kg}^{-1}$ ). Total nitrogen decreased by  $0.1 \text{ g kg}^{-1}$  in the T1 (Table 4.2).

The highest amount of phosphorus of  $69 \text{ mg kg}^{-1}$  was measured at Kongwa in T4 and T2, which were noted to have the uppermost increase relative to the baseline value ( $62 \text{ mg kg}^{-1}$ ). The smallest change in P was recorded in T3 ( $0.19 \text{ mg kg}^{-1}$ ) and T5 ( $1.25 \text{ mg kg}^{-1}$ ). At Bahi the results show that available phosphorus dropped by  $0.07 \text{ mg kg}^{-1}$  in T3,  $0.1 \text{ mg kg}^{-1}$  in T5 and T6 as well as by  $0.18 \text{ mg kg}^{-1}$  in T1. In contrast, it increased by  $1.21 \text{ mg kg}^{-1}$  and  $1.10 \text{ mg kg}^{-1}$  in T4 and T2, respectively (Table 4.2).

At the Kongwa site the highest amount of potassium in  $\text{cmol kg}^{-1}$  was measured in the Sun hemp-Sunflower intercropped plots: T3 (0.41), T5, and T4 (0.40), whereas T1 recorded the least K value of  $0.33 \text{ cmol kg}^{-1}$ . On the other hand, at Bahi, a higher amount of K of  $0.14 \text{ cmol kg}^{-1}$  was recorded in T3, and T2 compared to the other treatments where a value of  $0.12 \text{ cmol kg}^{-1}$  was noted. Based on calcium, at the Kongwa site, T3 recorded the highest percentage increase of 18% relative to the baseline value, followed by T5, T2, and T4 which recorded a 17% increase,

whereas at Bahi the percentage increase was 15% in T6 and T1, 17% in T4, and 18% in T2, T5 and T3 (Table 4.2).

At the Kongwa site, 0.02 cmol kg<sup>-1</sup> of magnesium in T1, T3, T4, and T5, 0.04 cmol kg<sup>-1</sup> in T2, and 0.01 cmol kg<sup>-1</sup> in T6 were found to have been added to the soil compared to its initial amount (0.20 cmol kg<sup>-1</sup>) before the start of the experiment. On the other hand, at the Bahi site, 0.04, 0.06, 0.05, 0.03, 0.01 cmol Mg kg<sup>-1</sup> in T1, T2, T3, T4, and T5 respectively were added to the soil relative to the baseline value of 0.22 cmol Mg kg<sup>-1</sup>. At Kongwa, sodium was found to have decreased in the order of T1 (0.22 cmol Na kg<sup>-1</sup>) < T6 (0.24 cmol Na kg<sup>-1</sup>) < T4 and T5 (0.25 Na cmol kg<sup>-1</sup>) < T3 (0.26 Na cmol kg<sup>-1</sup>) < T2 (0.29 Na cmol kg<sup>-1</sup>). On the other hand, Bahi Na was in the order T1 (0.20 cmol Na kg<sup>-1</sup>) < T2 and T5 (0.22 cmol Na kg<sup>-1</sup>) < T4 and T6 (0.230 cmol Na kg<sup>-1</sup>) < T3 (0.29 cmol Na kg<sup>-1</sup>).

Table 4.2: Soil chemical properties for Kongwa and Bahi sites (at 0–0.3 m depth) at the end of the experiment in April 2022

Site	Treatment	pH	Carbon (g kg <sup>-1</sup> )	Nitrogen (g kg <sup>-1</sup> )	Phosphorus (mg kg <sup>-1</sup> )	Potassium (cmol kg <sup>-1</sup> )	Calcium (cmol kg <sup>-1</sup> )	Magnesium (cmol kg <sup>-1</sup> )	Sodium (cmol kg <sup>-1</sup> )
Kongwa	T1	7.13 ± 0.06 <sup>a</sup>	4.8 ± 0.11 <sup>c</sup>	0.4 ± 0.01 <sup>a</sup>	62.35 ± 8.33 <sup>c</sup>	0.33 ± 0.04 <sup>c</sup>	1.70 ± 0.26 <sup>a</sup>	0.22 ± 0.102 <sup>a</sup>	0.22 ± 0.000 <sup>a</sup>
	T2	7.12 ± 0.07 <sup>a</sup>	6.0 ± 0.07 <sup>a</sup>	2.1 ± 0.02 <sup>a</sup>	68.56 ± 8.15 <sup>a</sup>	0.39 ± 0.07 <sup>ab</sup>	1.98 ± 0.17 <sup>a</sup>	0.24 ± 0.131 <sup>a</sup>	0.29 ± 0.056 <sup>a</sup>
	T3	6.85 ± 0.06 <sup>b</sup>	6.2 ± 0.07 <sup>a</sup>	0.6 ± 0.00 <sup>a</sup>	66.96 ± 9.18 <sup>a</sup>	0.41 ± 0.05 <sup>a</sup>	1.85 ± 0.19 <sup>a</sup>	0.22 ± 0.114 <sup>a</sup>	0.26 ± 0.021 <sup>a</sup>
	T4	7.11 ± 0.06 <sup>a</sup>	5.5 ± 0.09 <sup>b</sup>	0.5 ± 0.00 <sup>a</sup>	69.00 ± 8.48 <sup>a</sup>	0.40 ± 0.07 <sup>a</sup>	1.85 ± 0.30 <sup>a</sup>	0.22 ± 0.109 <sup>a</sup>	0.25 ± 0.025 <sup>a</sup>
	T5	6.92 ± 0.06 <sup>b</sup>	5.4 ± 0.09 <sup>b</sup>	0.5 ± 0.01 <sup>a</sup>	66.09 ± 8.81 <sup>ab</sup>	0.40 ± 0.05 <sup>a</sup>	1.80 ± 0.16 <sup>a</sup>	0.22 ± 0.112 <sup>a</sup>	0.25 ± 0.026 <sup>a</sup>
	T6	6.90 ± 0.02 <sup>b</sup>	4.9 ± 0.11 <sup>bc</sup>	0.4 ± 0.00 <sup>a</sup>	63.41 ± 10.84 <sup>bc</sup>	0.35 ± 0.05 <sup>bc</sup>	1.68 ± 0.15 <sup>a</sup>	0.21 ± 0.090 <sup>a</sup>	0.24 ± 0.033 <sup>a</sup>
LSD		0.08	0.5	0.14	3.15	0.05	0.1	0.033	0.042
<i>p</i> value		< 0.001	< 0.001	0.38	0.002	0.02	0.099	0.486	0.07
Bahi	T1	6.26 ± 0.01 <sup>a</sup>	4.2 ± 0.05 <sup>b</sup>	0.3 ± 0.01 <sup>c</sup>	11.82 ± 1.25 <sup>a</sup>	0.12 ± 0.01 <sup>b</sup>	2.20 ± 0.469 <sup>a</sup>	0.22 ± 0.020 <sup>c</sup>	0.20 ± 0.017 <sup>a</sup>
	T2	6.26 ± 0.11 <sup>a</sup>	4.8 ± 0.04 <sup>a</sup>	0.5 ± 0.01 <sup>ab</sup>	13.10 ± 0.64 <sup>a</sup>	0.14 ± 0.01 <sup>a</sup>	2.60 ± 0.748 <sup>a</sup>	0.26 ± 0.030 <sup>bc</sup>	0.22 ± 0.016 <sup>a</sup>
	T3	6.18 ± 0.08 <sup>b</sup>	4.9 ± 0.07 <sup>a</sup>	0.5 ± 0.01 <sup>b</sup>	11.90 ± 0.81 <sup>a</sup>	0.14 ± 0.00 <sup>a</sup>	2.70 ± 0.476 <sup>a</sup>	0.28 ± 0.027 <sup>a</sup>	0.26 ± 0.030 <sup>a</sup>
	T4	6.26 ± 0.09 <sup>a</sup>	5.2 ± 0.03 <sup>a</sup>	0.6 ± 0.00 <sup>a</sup>	13.21 ± 0.97 <sup>a</sup>	0.12 ± 0.01 <sup>b</sup>	2.48 ± 0.724 <sup>a</sup>	0.27 ± 0.059 <sup>ab</sup>	0.23 ± 0.044 <sup>a</sup>
	T5	6.17 ± 0.09 <sup>b</sup>	4.8 ± 0.00 <sup>a</sup>	0.5 ± 0.01 <sup>ab</sup>	11.93 ± 1.13 <sup>a</sup>	0.12 ± 0.01 <sup>b</sup>	2.60 ± 0.440 <sup>a</sup>	0.25 ± 0.029 <sup>bc</sup>	0.22 ± 0.016 <sup>a</sup>
	T6	6.17 ± 0.08 <sup>b</sup>	4.2 ± 0.04 <sup>b</sup>	0.4 ± 0.00 <sup>bc</sup>	11.90 ± 1.49 <sup>a</sup>	0.12 ± 0.01 <sup>b</sup>	2.18 ± 0.498 <sup>a</sup>	0.23 ± 0.011 <sup>bc</sup>	0.23 ± 0.025 <sup>a</sup>
LSD		0.031	0.5	0.09	0.715	0.012	0.395	0.038	0.032
<i>p</i> value		< 0.001	0.003	0.004	<.001	0.002	0.054	0.043	0.061

T1; Control (sunflower pure stand) without mineral nitrogen (N) fertilizer, T2; Sunflower-Sunn hemp intercrop under 1:1 row ratio without fertilizer, T3; Sunflower-Sunn hemp intercrop under 1:1 row ratio with fertilizer, T4; Sunflower-Sunn hemp intercrop under 2:1 row ratio without fertilizer, T5; Sunflower-Sunn hemp intercrop under 2:1 row ratio with fertilizer and T6; Sunflower pure stand with fertilizer. Down the column and within the same site, means followed by different letters differ significantly at  $p \leq 0.05$ .

#### **4.4 Effects of Sunflower-Sunn Hemp Intercropping Coupled with Mineral Nitrogen Fertilizer on Sunflower Growth and Yield Parameters**

##### ***4.4.1 Effects on sunflower growth parameters***

Plant height, number of leaves per plant, leaf area sunflower head diameter, and nitrogen uptake were significantly ( $p \leq 0.05$ ) affected by Sunn hemp intercropping coupled with mineral N fertilizer application with greater effects being noted in Kongwa than Bahi. For instance, in Kongwa at the vegetative stage, the highest sunflower plant height was recorded in T3 (88 cm) and T6 (83 cm) whereas intermediate values were noted in T4 (74 cm), T5 (73 cm), and T2 (60 cm), with control treatment (T1) having the least height of 34 cm (Fig. 4.2). At tasseling stage, the sunflower plant height was such that T1 (85 cm) < T2 (102 cm) < T5 (121 cm) < T4 (133 cm) < T3 (155 cm) < T6 (157 cm). A similar scenario was depicted at maturity with plant height ranging from 125 cm in T1 to 169 cm in T6.

On the other hand, in Bahi, at the vegetative stage, plant height was 11, 15, 16, 17, and 19% lower in T1, T2, T4, T5, and T6, respectively compared to T3 (Fig. 4.2). At the tasseling stage, plant height was lowest in T1 (73 cm) and T5 (85 cm), and highest in T3 (109 cm) and T6 (104 cm). At maturity, sunflower plant height in T5, T2, T4, T6, and T3 were observed to be significantly higher by 16, 16, 17, 18, and 14%, respectively relative to T1.

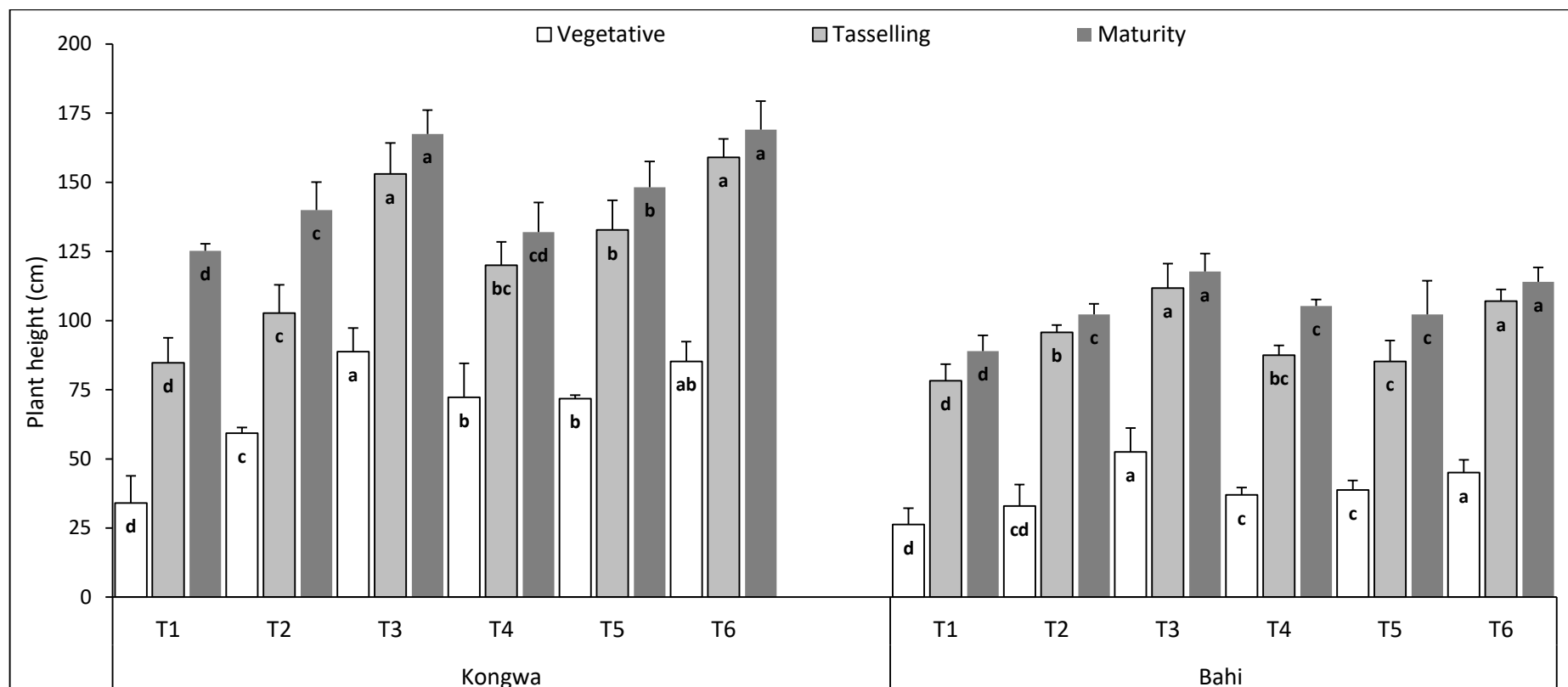


Figure 4.2: Sunflower plant height at vegetative (white bars), tasseling (grey bars), and maturity (black bars) development stages at Kongwa and Bahi during the 2021/2022 crop growing season as influenced by mineral nitrogen (N) fertilizer under different sunflower-Sunn hemp planting patterns: T1; Control (sunflower pure stand) without fertilizer, T2; Sunflower-Sunn hemp intercrop under 1:1 row ratio without fertilizer, T3; Sunflower-Sunn hemp intercrop under 1:1 row ratio with fertilizer inputs, T4; Sunflower-Sunn hemp intercrop under 2:1 row ratio without fertilizer, T5; Sunflower-Sunn hemp intercrop under 2:1 row ratio with fertilizer and T6; Sunflower pure stand with fertilizer. Bars bearing similar alphabet letters within the same crop development stage and site represent means that do not differ significantly at  $p \leq 0.05$ . Error bars indicate the standard error of the means.

Based on the sunflower leaf area, at Kongwa at the vegetative stage, the parameter was highest in T3 (285 cm<sup>2</sup>) and T6 (282 cm<sup>2</sup>) with T4 having the least value of 149 cm<sup>2</sup> (Fig. 4.3). At the tasselling stage, the leaf area decreased in the respective order of 567 > 497 > 393 > 339 > 294 > 218 cm<sup>2</sup> in T6, T3, T5, T4, T2, and T1, respectively. Similarly, at the maturity stage, the least leaf area (367 cm<sup>2</sup>) was noted in T1 whereas the uppermost values were recorded in T6 (607 cm<sup>2</sup>) and T3 (617 cm<sup>2</sup>). At the vegetative stage in Bahi, the sunflower leaf area was such that T2 (133 cm<sup>2</sup>) < T4 (134 cm<sup>2</sup>) < T5 (147 cm<sup>2</sup>) < T1 (155 cm<sup>2</sup>) < T6 (186 cm<sup>2</sup>) < T3 (253 cm<sup>2</sup>) (Fig. 4.3). At the tasselling stage, the leaf area had a range of 222 cm<sup>2</sup> in T4 to 283 cm<sup>2</sup> in T6. A congruent observation was made at maturity where the parameter remained highest in T6 (208 cm<sup>2</sup>) and T3 (196 cm<sup>2</sup>) with the other treatments: T1, T2, T4, and T5 having respective values of 133, 173, 170, 165 cm<sup>2</sup>.

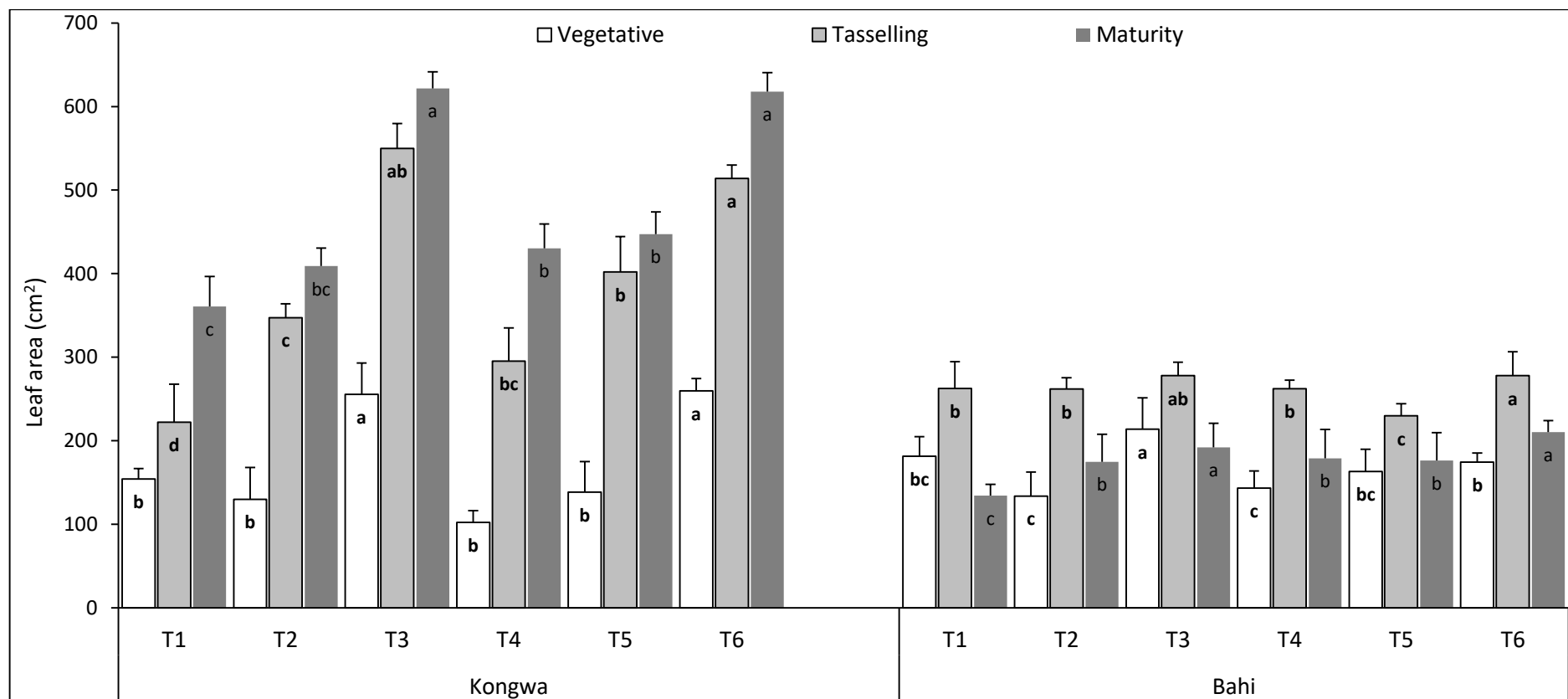


Figure 4.3: Sunflower leaf area at vegetative (white bars), tasselling (grey bars), and maturity (black bars) development stages at Kongwa and Bahi during the 2021/2022 crop growing season as influenced by mineral nitrogen (N) fertilizer under different sunflower-Sunn hemp planting patterns: T1; Control (sunflower pure stand) without fertilizer, T2; Sunflower-Sunn hemp intercrop under 1:1 row ratio without fertilizer, T3; Sunflower-Sunn hemp intercrop under 1:1 row ratio with fertilizer inputs, T4; Sunflower-Sunn hemp intercrop under 2:1 row ratio without fertilizer, T5; Sunflower-Sunn hemp intercrop under 2:1 row ratio with fertilizer and T6; Sunflower pure stand with fertilizer. Bars bearing similar alphabet letters within the same crop development stage and site represent means that do not differ significantly at  $p \leq 0.05$ . Error bars indicate the standard error of the means.

In Kongwa, at the vegetative stage, the number of sunflower leaves per plant in T6, T3, T4 and T5, and T2, was higher by 18, 18, 17 and 16% compared to T1 plots (Fig. 4.4). At the tasselling stage, the average number of leaves were 27.6, 24.5, 31.1, 25.9, 26.3, and 29.4 for T1, T2, T3, T4, T5, and T6 respectively. However, at maturity, a slightly different order was noted and it was such that T6 (26.8) > T3 (26.5) > T5 (24.7) > T1 (24.3) > T4 (23.8) > T2 (22.1). On the other hand, in Bahi, at the vegetative stage, the average number of leaves ranged from 19.6 for T1 to 21.3 for T6 (Fig. 4.4). A comparable trend (T1 < T5 < T3 < T2 < T3 < T6) was noted at tasselling and maturity stages with respective ranges of 25–28 and 19–21 number of leaves per sunflower plant.

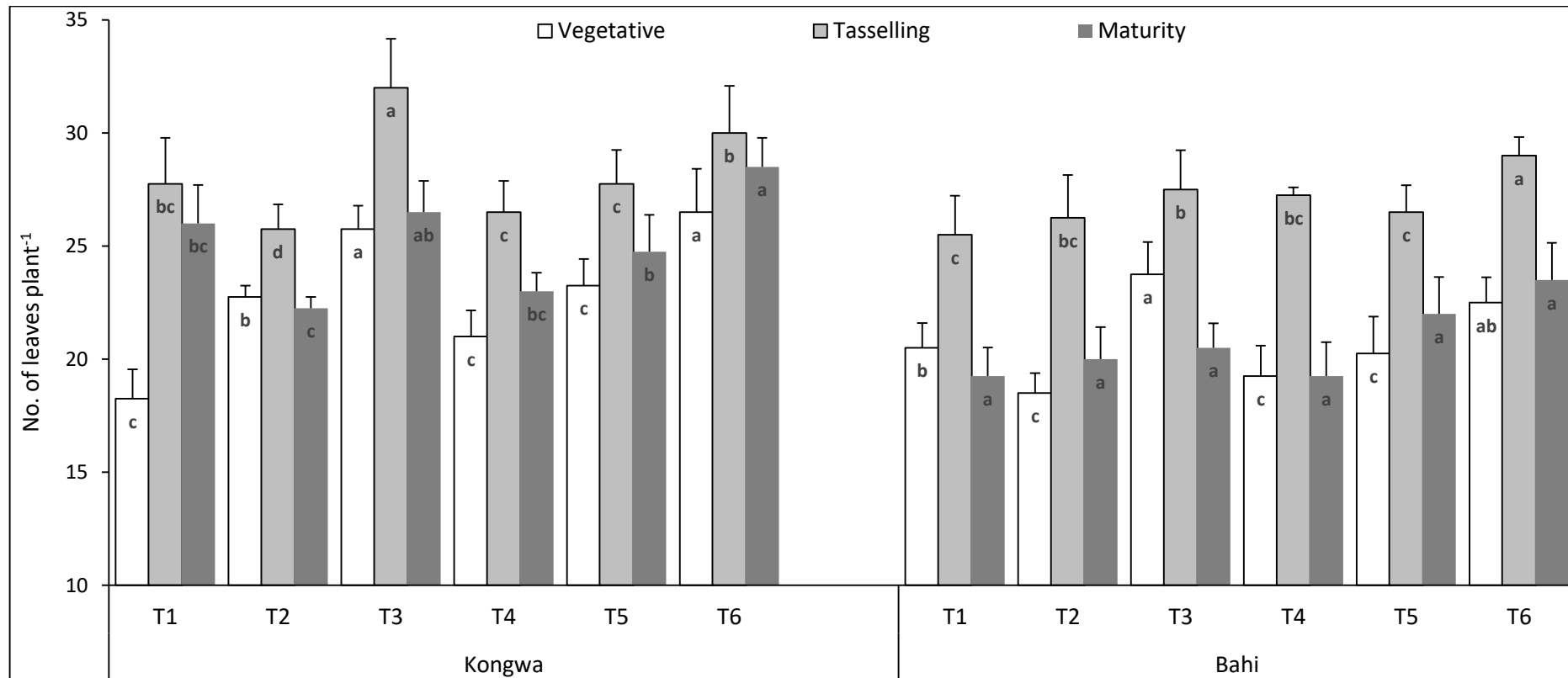


Figure 4.4: Number of leaves per sunflower plant at vegetative (white bars), tasselling (grey bars), and maturity (black bars) development stages at Kongwa and Bahi during the 2021/2022 crop growing season as influenced by mineral nitrogen (N) fertilizer under different Sunflower-Sunn hemp planting patterns: T1; Control (sunflower pure stand) without fertilizer, T2; Sunflower-Sunn hemp intercrop under 1:1 row ratio without fertilizer, T3; Sunflower-Sunn hemp intercrop under 1:1 row ratio with fertilizer, T4; Sunflower-Sunn hemp intercrop under 2:1 row ratio without fertilizer, T5; Sunflower-Sunn hemp intercrop under 2:1 row ratio with fertilizer and T6; Sunflower pure stand with fertilizer. Bars bearing similar alphabet letters within the same crop development stage and site represent means that do not differ significantly at  $p \leq 0.05$ . Error bars indicate the standard error of the means.

Concerning sunflower head diameter, at Kongwa, T6, T3, T5, T2, and T4 had higher values by 20,19, 17, 16, and 15%, respectively compared to T1 (Fig. 4.5). Lower values were noted for this parameter in Bahi whereby in comparison to control the other treatments had head diameters that were longer by 14–18%.

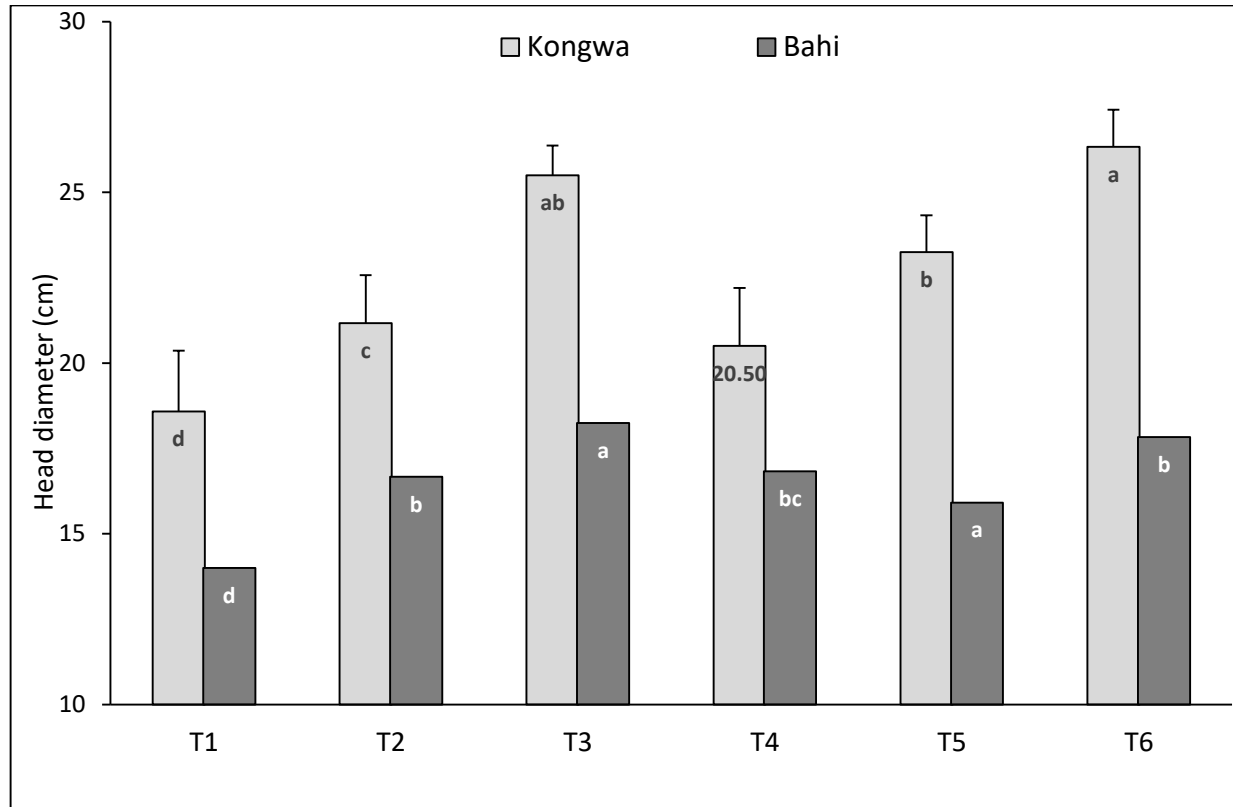


Figure 4.5 sunflower head diameter in Kongwa and Bahi sites during the 2021/2022 crop growing season as affected by mineral N fertilizer under different sunflower-Sunn hemp planting patterns: T1; Control (sunflower pure stand) without fertilizer, T2; Sunflower-Sunn hemp intercrop under 1:1 row ratio without fertilizer, T3; Sunflower-Sunn hemp intercrop under 1:1 row ratio with fertilizer, T4; Sunflower-Sunn hemp intercrop under 2:1 row ratio without fertilizer, T5; Sunflower-Sunn hemp intercrop under 2:1 row ratio with fertilizer and T6; Sunflower pure stand with fertilizer. Bars bearing similar alphabet letters within the same site represent means that do not differ significantly at  $p \leq 0.05$ . Error bars indicate the standard error of the means.

Nitrogen uptake at the Kongwa site was noted to have increased in the order of T1 ( $8.1 \text{ g kg}^{-1}$ ) < T6 ( $12.2$ ) < T5 ( $13.8 \text{ g kg}^{-1}$ ) < T2 ( $14.0 \text{ g kg}^{-1}$ ) < T4 ( $14.6 \text{ g kg}^{-1}$ ) < T3 ( $17.2$ ) (Fig. 4.6). On the other hand, at Bahi it increased in the order of T1 ( $5.0 \text{ g kg}^{-1}$ ) < T6 ( $7.6 \text{ g kg}^{-1}$ ) < T2 ( $8.5 \text{ g kg}^{-1}$ ) < T4 and T5 ( $8.6 \text{ g kg}^{-1}$ ) < T3 ( $9.8 \text{ g kg}^{-1}$ ).

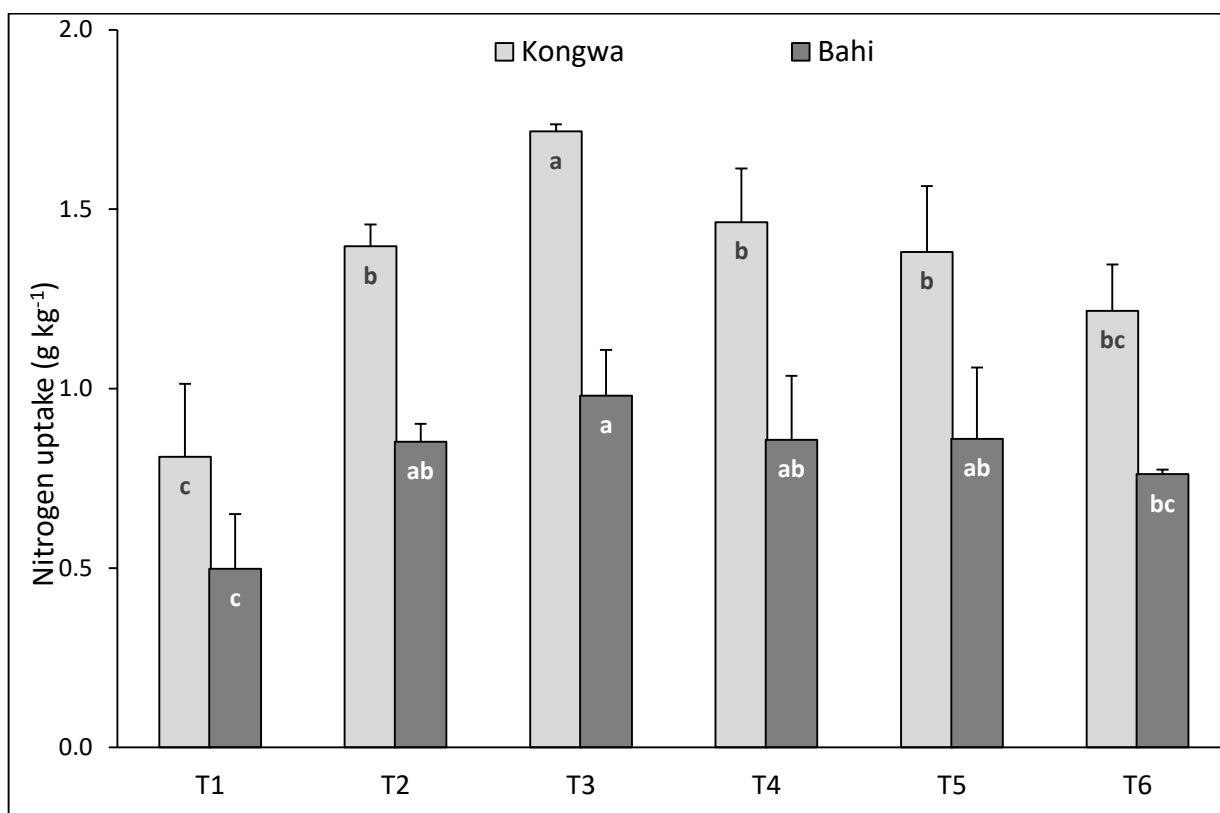


Figure 4.6: Sunflower nitrogen uptake in Kongwa and Bahi sites during the 2021/2022 crop growing season as influenced by mineral N fertilizer under different sunflower-Sunn hemp planting patterns: T1; Control (sunflower pure stand) without fertilizer, T2; Sunflower-Sunn hemp intercrop under 1:1 row ratio without fertilizer, T3; Sunflower-Sunn hemp intercrop under 1:1 row ratio with fertilizer, T4; Sunflower-Sunn hemp intercrop under 2:1 row ratio without fertilizer, T5; Sunflower-Sunn hemp intercrop under 2:1 row ratio with fertilizer and T6; Sunflower pure stand with fertilizer. Bars bearing similar alphabet letters within the same site represent means that do not differ significantly at  $p \leq 0.05$ . Error bars indicate the standard error of the means.

#### 4.4.2 Effects on sunflower yield parameters

Sunflower achene yield, number of seeds per plant, the weight of seed per plant, and sunflower stover yield were significantly ( $p \leq 0.05$ ) affected by Sunn hemp intercropping coupled with N fertilizer application with the greater effect being noted in Kongwa than Bahi. For instance, at the Kongwa site, the sunflower yield differed between treatments where it increased in the order of T1 ( $2.8 \text{ t ha}^{-1}$ ) < T2 ( $3.5 \text{ t ha}^{-1}$ ) < T4 ( $4.1 \text{ t ha}^{-1}$ ) < T5 ( $4.7 \text{ t ha}^{-1}$ ) < T6 ( $5.0 \text{ t ha}^{-1}$ ) < T3 ( $5.2 \text{ t ha}^{-1}$ ) (Table 4.3). A congruent trend was witnessed in Bahi with achene yield ranging from  $1.39 \text{ t ha}^{-1}$  in T1 to  $2.7 \text{ t ha}^{-1}$  in T3.

The highest number of sunflower seeds per plant (in Kongwa) was recorded in T3 (1879) whereas T1 had the lowest value at 1027 (Table 4.3). In Bahi, the highest record of sunflower seeds per

plant was made from T3 (968) and T6 (949), followed by T2, T4, and T5 with intermediate values of 779, 785, and 708 respectively, then the lowest value of 485 was recorded in T1.

The highest weight of seeds per plant was recorded at the Kongwa in T3 (106 g), T6 (113 g), and T5 (107 g) followed by T4 (91 g) and T2 (78 g) whereas the lowest value was recorded in T1 (63 g) (Table 4.3). For Bahi, the heaviest seeds were noted in T3 (60 g) and T6 (58 g), whereas T1 had the lightest seeds (31 g). At Kongwa, stover yield (in t ha<sup>-1</sup>) increased in the order of T1 (17) < T2 (25) < T4 (26) < T5 (39) < T6 (49) < T3 (69) (Table 4.3). The stover yield at Bahi was highest in T3 and T6 with a mean of 13 t ha<sup>-1</sup> and least in T1 (8 t ha<sup>-1</sup>).

Table 4.3: Sunflower yield parameters as influenced by mineral nitrogen fertilizer under different Sunflower-Sunn hemp planting patterns at Kongwa and Bahi sites in the 2021/2022 crop growing season

Site	Treatment	Weight of seeds plant <sup>-1</sup> (g)	Achene yield (t ha <sup>-1</sup> )	Number of seeds plant <sup>-1</sup>	Stover yield (t ha <sup>-1</sup> )
Kongwa	T1	63.33 ± 29 <sup>d</sup>	2.81 ± 1.29 <sup>d</sup>	1026.75 ± 50 <sup>d</sup>	17.38 ± 6.33 <sup>d</sup>
	T2	77.54 ± 19 <sup>c</sup>	3.45 ± 0.84 <sup>c</sup>	1252.08 ± 30 <sup>c</sup>	25.43 ± 7.11 <sup>d</sup>
	T3	116.33 ± 4 <sup>a</sup>	5.17 ± 0.19 <sup>a</sup>	1879.25 ± 70 <sup>a</sup>	69.38 ± 26.37 <sup>a</sup>
	T4	91.17 ± 17 <sup>b</sup>	4.05 ± 0.76 <sup>bc</sup>	1479.33 ± 285 <sup>bc</sup>	26.14 ± 15.21 <sup>cd</sup>
	T5	106.33 ± 3 <sup>a</sup>	4.73 ± 0.12 <sup>b</sup>	1726.92 ± 34 <sup>b</sup>	38.78 ± 3.12 <sup>bc</sup>
	T6	113.42 ± 5 <sup>a</sup>	5.04 ± 0.22 <sup>ab</sup>	1827.17 ± 83 <sup>ab</sup>	49.44 ± 25.67 <sup>b</sup>
LSD		12.37	0.55	206.00	12.82
<i>p</i> value		< 0.001	< 0.001	< 0.001	< 0.001
Bahi	T1	31.25 ± 5 <sup>c</sup>	1.39 ± 0.21 <sup>c</sup>	485.08 ± 83 <sup>c</sup>	6.86 ± 0.52 <sup>d</sup>
	T2	48.21 ± 17 <sup>b</sup>	2.14 ± 0.77 <sup>b</sup>	779.25 ± 281 <sup>b</sup>	10.56 ± 4.67 <sup>b</sup>
	T3	59.86 ± 16 <sup>a</sup>	2.66 ± 0.71 <sup>a</sup>	967.92 ± 258 <sup>a</sup>	13.34 ± 5.21 <sup>a</sup>
	T4	48.43 ± 13 <sup>b</sup>	2.15 ± 0.60 <sup>b</sup>	785.25 ± 212 <sup>b</sup>	10.60 ± 4.75 <sup>b</sup>
	T5	43.32 ± 6 <sup>b</sup>	1.93 ± 0.27 <sup>b</sup>	708.75 ± 93 <sup>b</sup>	8.16 ± 0.73 <sup>c</sup>
	T6	58.17 ± 17 <sup>a</sup>	2.59 ± 0.75 <sup>a</sup>	949.17 ± 270 <sup>a</sup>	13.26 ± 5.33 <sup>a</sup>
LSD		7.01	2.43	108	2.43
<i>p</i> value		< 0.001	< 0.001	< 0.001	< 0.001

T1; Control (sunflower pure stand) without mineral nitrogen (N) fertilizer, T2; Sunflower-Sunn hemp intercrop under 1:1 row ratio without fertilizer, T3; Sunflower-Sunn hemp intercrop under 1:1 row ratio with fertilizer, T4; Sunflower-Sunn hemp intercrop under 2:1 row ratio without fertilizer, T5; Sunflower-Sunn hemp intercrop under 2:1 row ratio with fertilizer and T6; Sunflower pure stand with fertilizer. Down the column and within the same site, means followed by different letters differ significantly at  $p \leq 0.05$ .

#### **4.5 Effects of Sunflower-Sunn Hemp Intercropping Coupled with Mineral Nitrogen Fertilizer on Economic Returns**

The total cost of production, gross income, net income, and benefit-cost ratio (BCR) differed among the treatments with significantly ( $p \leq 0.05$ ) higher economic returns being recorded in the Kongwa compared with the Bahi site. The highest (US\$ 278 ha<sup>-1</sup>) and the least (US\$ 205 ha<sup>-1</sup>) cost of production were recorded in T5 and T2, respectively with intermediate values being noted in T3 (US\$ 248 ha<sup>-1</sup>) and T4 (US\$ 235 ha<sup>-1</sup>) (Table 4.4). At the Kongwa site, the highest gross income was recorded in T3 (US\$ 3412 ha<sup>-1</sup>), and T6 (US\$ 3327 ha<sup>-1</sup>), whereas the least value (US\$ 1858 ha<sup>-1</sup>) was recorded in T1 (Table 4.5). On the other hand, at the Bahi site, the highest gross income of US\$ 1756 ha<sup>-1</sup> and US\$ 1706 ha<sup>-1</sup> were recorded in T3 and T6, respectively, with intermediate values being noted in T2 (US\$ 1414 ha<sup>-1</sup>), T4 (US\$ 1421 ha<sup>-1</sup>) and T5 (US\$ 1271 ha<sup>-1</sup>). T1 had the lowest record of gross income of US\$ 917 ha<sup>-1</sup>. Across the sites, the lowest net income was recorded in the control treatment. That is, Kongwa had a net income of US\$ 1639 with a BCR of 7.50 while the counterpart treatment at Bahi had respective values of US\$ 698 and 3.20 (Table 4.5).

Table 4.4: Variable cost for different treatments at Kongwa and Bahi sites in the 2021/2022 crop growing season

Site	Treatment	Land preparation	Land lease	Sunflower seeds	Sunn hemp seeds	Planting	Weeding	Pesticides	Fertilizers	Harvesting	Total
(US\$ ha <sup>-1</sup> )											
Kongwa	T1	17.4	54.3	32.6	0.0	13.0	34.8	33.7	0.0	32.6	218.4
	T2	17.4	54.3	32.6	14.8	17.4	23.9	3.5	0.0	41.3	205.2
	T3	17.4	54.3	32.6	14.8	17.4	23.9	3.5	42.8	41.3	248.0
	T4	17.4	54.3	32.6	29.6	21.7	28.2	3.5	0.0	47.5	234.8
	T5	17.4	54.3	32.6	29.6	21.7	28.2	3.5	42.8	47.5	277.6
	T6	17.4	54.3	32.6	0.0	13.0	34.8	33.7	42.8	32.6	261.2
Bahi	T1	17.4	54.3	32.6	0.0	13.0	34.8	33.7	0.0	32.6	218.4
	T2	17.4	54.3	32.6	14.8	17.4	23.9	3.5	0.0	41.3	205.2
	T3	17.4	54.3	32.6	14.8	17.4	23.9	3.5	42.8	41.3	248
	T4	17.4	54.3	32.6	29.6	21.7	28.2	3.5	0.0	47.5	234.8
	T5	17.4	54.3	32.6	29.6	21.7	28.2	3.5	42.8	47.5	277.6
	T6	17.4	54.3	32.6	0.0	13.0	34.8	33.7	42.8	32.6	261.2

T1; Control (sunflower pure stand) without mineral nitrogen (N) fertilizer, T2; Sunn hemp-sunflower intercrop under 1:1 row ratio without fertilizer, T3; Sunflower-Sunn hemp intercrop under 1:1 row ratio with fertilizer, T4; Sunflower-Sunn hemp intercrop under 2:1 row ratio without fertilizer, T5; Sunflower-Sunn hemp intercrop under 2:1 row ratio with fertilizer and T6; Sunflower pure stand with fertilizer.

Table 4.5: Gross income, net income, and benefit-cost ratio as influenced by mineral nitrogen fertilizer under different Sunflower-Sunn hemp planting patterns at Kongwa and Bahi sites in the 2021/2022 crop growing season

Site	Treatment	Gross income (US\$ ha <sup>-1</sup> )	Net income (US\$ ha <sup>-1</sup> )	Benefit-cost ratio
Kongwa	T1	1857.78 ± 854 <sup>d</sup>	1639.32 ± 854 <sup>d</sup>	7.50 ± 3.91 <sup>d</sup>
	T2	2274.58 ± 554 <sup>c</sup>	2069.29 ± 554 <sup>c</sup>	10.08 ± 2.70 <sup>c</sup>
	T3	3412.20 ± 123 <sup>a</sup>	3164.08 ± 123 <sup>a</sup>	12.75 ± 0.50 <sup>a</sup>
	T4	2674.22 ± 504 <sup>b</sup>	2439.33 ± 504 <sup>b</sup>	10.38 ± 2.15 <sup>bc</sup>
	T5	3119.11 ± 82 <sup>a</sup>	2841.39 ± 82 <sup>a</sup>	10.23 ± 0.30 <sup>bc</sup>
	T6	3326.89 ± 148 <sup>a</sup>	3065.60 ± 148 <sup>a</sup>	11.73 ± 0.57 <sup>ab</sup>
LSD		363.0	363.0	1.64
<i>p</i> value		< 0.001	< 0.001	< 0.001
Bahi	T1	916.67 ± 135 <sup>c</sup>	698.21 ± 135 <sup>d</sup>	3.20 ± 0.62 <sup>c</sup>
	T2	1414.11 ± 508 <sup>b</sup>	1208.82 ± 508 <sup>b</sup>	5.89 ± 2.47 <sup>ab</sup>
	T3	1755.84 ± 472 <sup>a</sup>	1507.72 ± 472 <sup>a</sup>	6.08 ± 1.90 <sup>a</sup>
	T4	1420.71 ± 395 <sup>b</sup>	1185.82 ± 395 <sup>bc</sup>	5.05 ± 1.68 <sup>b</sup>
	T5	1270.62 ± 181 <sup>b</sup>	992.90 ± 181 <sup>c</sup>	3.58 ± 0.65 <sup>c</sup>
	T6	1706.22 ± 495 <sup>a</sup>	1444.93 ± 495 <sup>a</sup>	5.53 ± 1.89 <sup>ab</sup>
LSD		205.6	205.6	0.91
<i>p</i> value		< 0.001	< 0.001	< 0.001

T1; Control (sunflower pure stand) without mineral nitrogen (N) fertilizer, T2; Sunflower-Sunn hemp intercrop under 1:1 row ratio without fertilizer, T3; Sunflower-Sunn hemp intercrop under 1:1 row ratio with fertilizer, T4; Sunflower-Sunn hemp intercrop under 2:1 row ratio without fertilizer, T5; Sunflower-Sunn hemp intercrop under 2:1 row ratio with fertilizer and T6; Sunflower pure stand with fertilizer. Down the column and within the same site, means followed by different letters differ significantly at  $p \leq 0.05$ .

#### **4.6. Relationship Among the Assessed Variables: Sunflower Growth, Yield, and Economic Parameters**

Sunflower plant height, significantly correlated with head diameter, number of seeds per plant, sunflower leaf area, nitrogen uptake, the weight of seeds per plant, achene yield, stover yield, gross income, and net income ( $r = 0.85 - 0.98$ ) (Table 4.6). Similarly, sunflower leaf area had direct correlations with the number of leaves and sunflower head diameters, the number of seeds per plant, the weight of seeds per plant, nitrogen uptake, sunflower yields, stover yields, gross and net income ( $r = 0.83-0.98$ ).

On the other hand, there were strong and positive relationships between sunflower head diameter and the number of seeds per plant, the weight of seeds per plant, nitrogen uptake, sunflower achene yield, stover yields, as well as gross and net income ( $r = 0.86 - 0.99$ ) (Table 4.6). Similarly, the number of seeds per plant exhibited positive relationships with the weight of seeds per plant, achene yield, gross income, net income, and stover yields ( $r = 0.86- 0.99$ ). Nevertheless, the correlation between the number of seeds per plant and N uptake was observed to be weak. The weight of seeds per plant had positive correlations with sunflower stover yield, yield, net income, and gross income ( $r =0.98 - 1.00$ ).

Table 4.6: Correlations (Pearson) among the growth (plant height, leaf area, no of leaves plant<sup>-1</sup>, head diameter, and nitrogen uptake), yield (No. of seeds plant<sup>-1</sup>, the weight of seeds plant<sup>-1</sup>, achene yield, and stover yield), and economic (gross income and net income) parameters

Parameter	Plant height	Leaf area	No of leaves plant <sup>-1</sup>	Head diameter	No. of seeds plant <sup>-1</sup>	Weight of seeds plant <sup>-1</sup>	Achene yield	Nitrogen uptake	Stover yields	Gross income
Leaf area	0.912***									
No of leaves plant <sup>-1</sup>	0.733**	0.834**								
Head diameter	0.979***	0.959***	0.768**							
No. of seeds plant <sup>-1</sup>	0.972***	0.980***	0.794**	0.996***						
Weight of seeds	0.972***	0.977***	0.769**	0.995***	0.999***					
achene yield	0.972**	0.978***	0.772**	0.995***	0.999***	0.999***				
Nitrogen uptake	0.851**	0.662*	0.678*	0.810**	0.672*	0.761*	0.760*			
Stover yields	0.921***	0.953***	0.645*	0.963***	0.967***	0.975***	0.975***	0.635*		
Gross income	0.972***	0.977***	0.769**	0.995***	0.999***	0.997***	1.000***	0.761*	0.975**	
Net income	0.963***	0.966***	0.725**	0.993***	0.993***	0.996***	0.996***	0.752*	0.985***	0.996***

Significant at  $p < 0.01$  (\*\*\*),  $p = 0.01$  (\*\*) and  $p \leq 0.05$  (\*).

## CHAPTER FIVE

### DISCUSSION

#### 5.1 Effects of Sunflower-Sunn Hemp Intercropping Coupled with the Application of Mineral Nitrogen Fertilizer on Soil Chemical Properties

Soil samples from the fields revealed statistically significant evidence of soil modification in all the plots where Sunn hemp was planted alongside sunflower. Nutrients were noted to increase in the treatments containing Sunn hemp legume. Probably this is because Sunn hemp has a long taproot. Such a deep rooting system might have facilitated Sunn hemp to take the nutrients beyond the root zone of Sunflower. Hence this reduced the nutrients lost through the process of leaching and fixation (Hopkins *et al.*, 2014; Gitari *et al.*, 2018; Fernandes and Soratto, 2012). *Crotalaria juncea* is the most popularly utilized legume as green manure under intercropping due to its rapid development, robust annual structure, upright stem, large biomass output, and ability to fix atmospheric N<sub>2</sub> and recycle various soil nutrients (Vargas *et al.*, 2011). Moura *et al.* (2005) and (Haile *et al.*, 2023) noted that any legume takes around 50 days to break down and release approximately 30% of N present in the plant material.

Total nitrogen was found to increase slightly in the soils of the plots that contained Sunn hemp. This could be because Sunn hemp undergoes biological nitrogen fixation thereby adding some amount of nitrogen to the soil. Such findings are in agreement with the earlier reports by Perin *et al.* (2006) in which they found that, in the maize-sunn hemp intercropping system, the Sunn hemp accumulated about 144 kg N ha<sup>-1</sup>. The nitrogen contents were reported to be much higher in the treatments of Sunn hemp which could be beneficial to the subsequent crop in the field (Vargas *et al.*, 2011). These results concur with those of Rotar and Joy (1983) and Mansoer *et al.* (1997) whereby Sunn hemp was reported to have added about 160 and 143 kg of N per ha, respectively after 60 to 70 days of its growth. Similar results were obtained by Ramos *et al.* (2001), which showed that Sunn hemp accumulated about 150 kg N ha<sup>-1</sup> under Maize-Sunn hemp intercropping. The results are also in agreement with Chappa *et al.* (2022), who revealed that the inclusion of legumes like Sunn hemp in an intercropping system could result in symbiotic N fixation and ultimately higher yield. Approximately, 38% of the N in biomass continued to be available for maize that was planted 16 weeks after mowing the Sunn hemp (Mansoer *et al.*, 1997).

The soil organic carbon in all the treatments containing Sunn hemp increased, compared to the other treatments. This could be ascribed to the ability of Sunn hemp to produce high biomass

which after decomposition increases the soil's organic carbon. These findings corroborate those of Freidenreich *et al.* (2022) in which Sunn hemp was reported to speed up the release of organic matter in cropping systems. Similarly, Bhayal *et al.* (2018) observed that intercropping Sunn hemp and soybeans resulted in increased soil organic carbon. When intercropped with maize, Winter legume (Sunn hemp) offers many benefits such as soil erosion control, enhanced water infiltration, increased organic C contents, as well as cooling the soil temperatures (Reeves, 1994). Sole sunflower treatments supplied with N fertilizers also showed a positive increase in soil organic carbon. This could be because of the nitrogen supplied which supported the biomass yield of the crops, in turn, increased the soil's organic carbon. Such results are also supported by Jin (2018), who confirmed that N fertilization increases the organic carbon of the soil profile. In the treatments without Sunn hemp, the organic carbon was confirmed to be low. Such an observation could be attributed to the low amount of biomass, as well as poor soil moisture which does not support organic matter decomposition.

It was discovered that all the plots with the integrated approach had high available phosphorus compared to the control. This could be due to the deep extensive roots of Sunn hemp which take residual phosphorus beyond the root zone. More so it could be associated with increased biomass production, which releases nutrients into the soil. These results also corroborate with those of Wang *et al.* (2011) who reported that Sunn hemp (*Crotalaria juncea*) accumulates a high amount of P and N because of its high production of biomass.

Exchangeable bases increased in all the treatments containing Sunn hemp after crop harvest. This could be because of the long tap rooting system of Sunn hemp which enabled it to take the residual exchangeable bases below the root zone. Such a phenomenon agrees with the results published by Dzvene *et al.* (2022) who demonstrated that Sunn hemp encourages the cycling of nutrients by boosting the activity of microbes hence the release of the nutrients. The soil pH was observed to be unaffected in the non-fertilized treatments, but some slight changes in the treatments that contained N fertilizers were observed. This could be attributed to the use of urea fertilizers which could have released protons that affected the soil reaction. Similar results have been reported by Shetty *et al.* (2019) who demonstrated that urea adds bicarbonate to the soil which reacts with soil H<sup>+</sup> ions hence lowering soil pH. In summary, the utilization of an integrated approach, such as the combination of Sunn hemp and mineral fertilizer, demonstrated a good effect on the chemical characteristics of the soil.

## **5.2 Effects of Sunflower-Sunn Hemp Intercropping Coupled with Mineral Nitrogen Fertilizer on Sunflower Growth and Yield Parameters**

There was measurable evidence that the treatments that contained Sunn hemp alone, mineral fertilizers alone, or combined Sunn hemp and N fertilizers, showed improvements in the plant height, leaf area, number of leaves, Sunflower head diameter, number of seeds per plant, the weight of seeds per plant, sunflower yield, nitrogen uptake, and sunflower stover yields. Under intercropping of Sunflower and Sunn hemp coupled with the application of nitrogenous there was improved growth and yield of sunflower. This could be attributed to the addition of nitrogen nutrients through the supplied nitrogenous fertilizers as well as by the Sunn hemp, through its process of nitrogen fixation (Chepkorir *et al.*, 2023). Again, all the treatments that contained Sunn hemp and nitrogenous fertilizers outperformed the control treatments in terms of sunflower plant height. Such could be attributed to the nitrogen nutrient supplied by the legume plant as well as the additional supply from the fertilizer (Heydarzadeh *et al.*, 2023; Mirriam *et al.*, 2023). Similar results were reported by Solemani *et al.* (2013), who confirmed that increasing nitrogen in the soil also increases the sunflower height. In addition, the results of this study agree with the findings of Abu-Alrub *et al.* (2014) and Alhammad *et al.* (2023a), who found that the use of nitrogen fertilizers in the soil led to a considerable rise in the height of buffel and Sudan grasses in contrast to the non-fertilized soil. Sunn hemp could also have helped in increasing the availability of nutrients to Sunflower due to its deep extensive root system that takes the nutrients beyond the root zone and pumps them to the topsoil layer. Sunn hemp provides additional benefits to sunflower such as conserving soil moisture (through its extensive crop cover) and suppressing pests, weeds, and diseases.

Regarding the sunflower leaf area, the results showed that in both locations, at all three sunflower growth phases, T6 and T3 had particularly large leaf areas. This could be because these treatments contained nutrients such as N from nutrients cycling by Sunn hemp which allowed the sunflower leaves to expand in width and length resulting in greater leaf area. These results are consistent with the findings of Nasar *et al.* (2021, 2022a), who found that nitrogen increased the photosynthetic activities of maize plants which improved the leaves' characteristics including leaf area and the number of leaves. Similarly, Iqbal *et al.* (2001) reported that some of the phenological sunflower parameters such as leaf area, the number of leaves per plant, head diameter, and height of the plant were maximized at the N level of 120 kg ha<sup>-1</sup>. Furthermore, the results are in line with those of Moghimi and Maghsoudi (2015) and Sher *et al.* (2016), who

discovered that sorghum cultivars with higher nitrogen rates produced more leaves and a big leaf area. The small leaf area in the other treatments like in the 2:1 intercropped treatment could be because of the spatial arrangements of the crops which did not support the full expansion of leaves. The same could be attributed to poor nutrients and moisture availability to support sunflower growth.

Concerning the number of leaves, the results showed, that there was a noticeable variation in the total number of leaves per plant between treatments and across all sunflower developmental phases. The highest number of leaves recorded in the fertilized Sunflower-Sunn hemp intercrop plots could be attributed to the nutrients that had been added to the soil, which supported the plant to bear a greater number of leaves. Similar results have been published by Ochieng' *et al.* (2021), Raza *et al.* (2022), and Chandler (2015) who observed that supplying plants with nitrogen increases their number of leaves and plant height. The greatest variation in the number of leaves per plant observed during the three stages could be attributed to the fact that the leaves are actively created during the vegetative stage, fully produced and active during the flowering stage, and drying up during the harvesting stage (De la Haba *et al.*, 2014).

Sunflower head diameter, number of seeds per plant, the weight of seeds per plant, and achene yield were noted to be significantly high in the plots of Sunflower-Sunn hemp intercropping under a 1:1 row ratio with fertilizer. This could have resulted from the release of nutrients by biological nitrogen fixation and nutrient cycling by Sunn hemp, and/or N fertilizer application that helped the sunflower to perform better in the mentioned parameters. In their field study, Olalde *et al.* (2000) presented similar results, where they reported that increasing nitrogen levels helps in increasing the production of biomass, seed yields, the number of achenes per capitulum, and head diameter. The results are also in agreement with Singh *et al.* (2000) who observed that increasing nitrogen application leads to an increase in oil contents, head diameter, as well as the number of seeds. A big head diameter leads to more number seeds (Babec *et al.*, 2020), then a high weight of seeds which finally achieves the highest sunflower achene yield.

In addition to the added nutrients, another probable explanation for improved yield parameters under intercropping coupled with N application is the spatial arrangement of the crops (Raza *et al.*, 2023). For instance in the 2:1 Sunn hemp-sunflower arrangement probably there was the competition for some natural resources like light and space (Jeranyama *et al.*, 2000; Gitari *et al.*, 2018b). On the other hand, in the control plots, the performance in the mentioned parameter was poor compared to all the treatments with N probably because of the limited nutrients and

moisture. It was noted that all the treatments with the highest plant height had good sunflower yields. This agrees with Kaya (2016) who confirmed that plant height indirectly affects seed yield through leaf area and petiole length, for that case sunflower yields depend on the performance of other sunflower growth parameters.

With regards to nitrogen uptake, it was observed to be high in T6 and T3 compared to other treatments. This could be attributed to the N fertilizers supplied in the soil as well as the biological nitrogen fixation performed by the Sunn hemp legume. Under such cases, the released nitrogen could have been taken up by the sunflower hence the highest nitrogen concentration in the leaves. This agrees with the article published by Hooks *et al.* (2007) who observed a high nitrogen content in the cucumber leaves, grown under Sunn hemp-cucumber intercropping system.

Based on the results obtained, T6 and T3 recorded the highest sunflower stover yields, which could be attributed to the nutrients supplied by the combination of N fertilizers and BNF by Sunn hemp. Similar results were reported by Dzvene *et al.* (2022) who confirmed that intercropping Sunn hemp with maize has substantial positive impacts on the amount of biomass produced by maize in terms of the yield. As documented by Cheptoek *et al.* (2021), Alhammad *et al.* (2022a), Chandler (2015), and Ochieng' *et al.* (2021), supplying plants with nitrogen increases their leaf number, plant height, leaf area, stem diameter, internode length, and the number of internodes hence high yield. The results show that the treatments that performed better in other parameters also have good performance in sunflower stover yields.

Across the sites, the Kongwa site showed good performance in sunflower growth parameters and yields, this could be because of the low temperature recorded at Kongwa which did not affect the availability of the limited soil moisture. This contrasts with the Bahi site, which was observed to have a high amount of temperature, which affected the availability of the limited soil moisture by evapotranspiration, leading to poor performance of the crops. Similar results have been published by Bhatt and Hossain (2019) whereby they observed that higher daytime temperatures cause a greater daily increase in the evaporative demand and consequently higher evapotranspiration rate. Drought stress especially high temperature significantly reduces many aspects of yield, including 1000-achene weight, capitulum diameter, achene weight per capitulum, and achene number per capitulum (Tyagi and Dhillon, 2015; Seleiman *et al.*, 2021; Goher *et al.*, 2023; Majeed *et al.*, 2023).

### **5.3 Effects of Sunflower-Sunn Hemp Intercropping Coupled with Mineral Nitrogen Fertilizer on Economic Returns**

High crop yield is the most important result of crop production since it leads to greater benefit-cost ratios and economic returns (Raza *et al.*, 2023; Cheptoek, 2022). This research showed that different factors had significant effects on sunflower crop performance in the field, which in turn affected sunflower yield and the crop's economic worth. Poor economic return was noted in the control treatment. The reason behind this could be the limited nutrients and moisture to support sunflower yield, which resulted in low economic returns. The treatments that had an integrated approach, including intercropped ones showed high economic returns compared to the control. Similar results were published by Ahmed and Hefzy (2020), who agreed that the intercropped sunflower and legume beans resulted in high economic returns compared to pure stand sunflower. The results also are in agreement with those of Hooks *et al.* (2007) who reported that intercropping cucumber and Sunn hemp, resulted in high cucumber yields hence high economic returns. Similarly, Olalde *et al.* (2000) in their article they reported that increasing nitrogen levels helps in increasing sunflower seed yields which also increases economic return.

The net income was higher and almost the same in fertilized sole sunflower treatments and the treatments of fertilized 1:1 Sunn hemp + sunflower. This was because the income of Sunn hemp was not factored in as an immediate economic return (Dzvene *et al.*, 2022). Otherwise, by putting the Sunn hemp income, all the intercropped treatments would have shown high profit compared to sole sunflower treatments.

At Kongwa, the generally better performance in terms of yields and economic returns than at Bahi could be ascribed to the low temperature recorded at Kongwa, which probably did not affect the availability of the limited soil moisture. In contrast, the Bahi site was observed to have a high ambient temperature, which must have affected the availability of the limited soil moisture by evapotranspiration, leading to poor performance of the crop and hence poor yield which resulted in poor sunflower economic returns. Flower anthesis and initiation are critical growth stages in sunflower production (Göksoy *et al.*, 2004; Hussain *et al.*, 2015) because the number of florets and the fertile flowers determines the achene yield. The high temperature at this stage of development reduces pollen viability, causing smaller heads, and reducing yields (Khalilvand *et al.*, 2007; Benlloch-González *et al.*, 2015; Göksoy *et al.*, 2004; Elsheikh *et al.*, 2015). Many aspects of yield, such as head diameter, number of achenes per head, the weight of seed per

capitulum, and 1000-achene weight, are drastically reduced by drought stress (Tyagi and Dhillon, 2015).

#### **5.4 Relationship Among the Assessed Variables**

Sunflower plant height strongly correlated with sunflower head diameter, the number of seeds per plant, sunflower leaf area, nitrogen uptake, the weight of seeds per plant, achene yield, stover yield, gross income, and net income. This indicated that the higher the plant height the more the leaves which lead to a high rate of photosynthetic activities hence good performance of the plant in other parameters. It was noted that all the plants with high plant height performed better in other growth parameters and economic returns. Kaya (2016) confirmed that plant height indirectly affects seed yield through leaf area and petiole length, for that case sunflower yields depend on the performance of other sunflower growth parameters. Tyagi and Dhillon (2015) also observed that sunflower plant height has a strong relationship with head diameter, which also affects other parameters like the number of seeds, gross income, the weight of seeds, yields, and net income.

The direct correlations of the Sunflower leaf area with the number of leaves and sunflower head diameters, the number of seeds per plant, the weight of seeds per plant, nitrogen uptake, sunflower yields, stover yields, gross and net income could be due to the big the leaf area. With a large leaf area, it is expected that there are more photosynthetic activities which ultimately results in high growth and finally affects the yield parameters as well as economic return. Earlier studies by Tyagi and Dhillon (2015) reported similar results, that sunflower leaf area had indirect impacts on sunflower growth parameters, yields as well as economic return.

The positive strong relationships between sunflower head diameter and the number of seeds per plant, the weight of seeds per plant, sunflower achene yield, and stover yields, as well as with gross and net income, is associated with the size of the sunflower head. Consequently, this impacts the number of seeds, the weight of seeds, and achene yield (Babec *et al.*, 2020), as well as gross and net incomes. Similarly, as noted by Balalić (2016), sunflower seed yield is equally affected by head size, which determines both the number of seeds per head and the average size of those seeds.

The number of seeds per plant exhibited positive relationships with the weight of seeds per plant, achene yield, gross income, net income, and stover yields. This was an indication that the more the number of seeds the higher the achene yield and the higher the gross and net income. Earlier, Tyagi and Dhillon (2015) confirmed that the number of seeds per plant leads to positive impacts

on other parameters. Nevertheless, the correlation between the number of seeds per plant and N uptake was observed to be weak. Such an observation was not a surprise since N uptake was analyzed from the leaves and not from the seeds. The observed positive correlations between the weight of seeds per plant and sunflower stover yield, yield, net income, and gross income could be ascribed to the higher weight of the seeds (Hladni *et al.*, 2016). This translated into high net income and gross income.

## CHAPTER SIX

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Conclusions

This study sought to improve soil chemical properties, sunflower production, and economic returns using integrated approaches (Sunflower-Sunn hemp intercropping or Sunflower-Sunn hemp intercropping in combination with mineral N fertilizer). It intended to find out the most ideal approach in sunflower production that would improve its growth, yield, and profitability. The study showed that Sunflower can grow and produce optimally besides giving higher economic returns, particularly when it is intercropped with legumes such as Sunn hemp coupled with the application of nitrogenous fertilizer. It is anticipated that the increased production of sunflower would help in improving the economic returns of the impoverished smallholder farmers, hence reducing poverty.

#### 6.2 Recommendations

This research suggests the following:

- The study recommends that sunflower growers consider the integration of Sunn hemp as an intercrop coupled with the application of mineral N fertilizer for not only optimal sunflower production and economic returns but also improved soil fertility.
- The study suggests that farmers who can't afford mineral fertilizers can use Sunn hemp to get high sunflower yields and improve soil fertility.
- When figuring out the economic returns, this study recommends that future studies ought to take Sunn hemp yields into account.
- Since this study was conducted for only one season, though in two sites, the study recommends a multiple-site study for an extended period. This would give a more comprehensive report on Sunflower-Sunn hemp intercropping practices and their accrued benefits.

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## APPENDICES

### Appendix I: Approval of Research Proposal



#### KENYATTA UNIVERSITY GRADUATE SCHOOL

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P.O. Box 43844, 00100  
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#### Internal Memo

**FROM:** Dean, Graduate School

**DATE:** 30<sup>th</sup> June, 2022

**TO:** Ms. Chappa Raphael  
C/o Department of Agricultural  
Science & Technology

**REF:** A148EA/21760/2020

**SUBJECT: APPROVAL OF RESEARCH PROPOSAL**

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This is to inform you that Graduate School Board, at its meeting on 20<sup>th</sup> June, 2022, approved your Research Proposal for the M.Sc. Degree entitled, "Soil Physiochemical Properties, Sunflower (*Helianthus annuus.*) Yield and Profitability Under Intercropping with Sunn Hemp and Mineral Fertilizer Application in Dodoma, Tanzania."

You may now proceed with your Data collection, subject to clearance with the Director General, National Commission for Science, Technology & Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed Supervision Tracking and Progress Report Forms per semester. The forms are available at the University's Website under Graduate School webpage downloads.

Also, please ensure that you publish article(s) from your thesis before submitting it to Graduate School for examination as per the Commission for University Education and Kenyatta University guidelines.

Thank you.

**REUBEN MURIUKI**  
**FOR: DEAN, GRADUATE SCHOOL**



**CC.** Chairman, Department of Agricultural Science & Technology  
**Supervisors:**

1. Prof. Jayne Mugwe  
C/o Department of Agricultural Science & Technology  
Kenyatta University
2. Dr. Harun Gitari  
C/o Department of Agricultural Science & Technology  
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