EFFECTS OF SPACING AND NEGARIM MICRO CATCHMENT ON THE GROWTH OF TWO PROVENANCES OF MORINGA (*Moringa oleifera*) IN KITUI COUNTY, SOUTH EASTERN KENYA.

DESMOND OBALA

B406/MAC/20001/2017

A Thesis submitted in partial fulfilment of the requirements for the Degree of Master of Science in Environmental Management of South Eastern Kenya University

2023

DECLARATION

I understand that plagiarism is an offence and I therefore declare that this Thesis Report is my original work and has not been presented to any other institution for any other award.

Signature: Date: **16/08/2022**

Desmond Obala

Reg. No.: B406/MAC/20001/2017

This Thesis Report has been submitted for examination with our approval as University Supervisors.

Signature: Date: **19/08/2022**

Dr. Felista W. Muriu-Ng'ang'a, PhD

Lecturer, South Eastern Kenya University

Department of Environmental Science and Land Resources Management

Signature: Date: **19/08/2022**

Dr. Harun Kiruki, PhD

Lecturer, South Eastern Kenya University

Department of Environmental Science and Land Resources Management

ACKNOWLEDGEMENT

I give thanks to God for my health and strength. My parents, Mr. Jeremiah Obala Oyulu and Mrs. Rose Ingolo, as well as my supervisors, Drs. Felista Muriu-Ng'ang'a and Harun Kiruki who deserve special appreciation. Mr. Danson Kioko, my field technician, and Dr. Festus Mutiso for the mentorship. Last but not least, the National Research Fund, whose project I conducted my research for. I owe a great deal of gratitude to Dr. Charles Ndung'u, the lead researcher on the Smart Agriculture Project, who provided the financing for this study.

DEDICATION

I dedicate this work and all the time it took to perfect it to my lovely parents, Mr. Jeremiah Obala Oyulu and Mrs. Rose Ingolo Obala. May you never lack any of desires.

TABLE OF CONTENTS

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

CHAPTER SIX

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS AND ACRONYMS

°C	:	Degrees Celsius
%	:	Percent
ANOVA	:	Analysis of Variance
cm	:	Centimetres
df	:	Degree of freedom
Km	:	Kilometres
M	:	Meters
m.s.	:	Mean of Squares
mm	:	Millimeters
RCBD	:	Randomized Complete Block Design
Sig.	:	Significance (*p* – value)
s.s.	:	Sum of squares

ABSTRACT

There has been an increased human population in arid and semi-arid areas. However, these areas are characterized by harsh climatic conditions hence low agricultural productivity, environmental degradation and over exploitation of natural resources. There's need to understand the best agronomic crop requirements for high value trees and shrubs like *Moringa oleifera* (Lamark) through climate smart agriculture. Limited studies on *Moringa oleifera* provenance trials, use of micro-catchments and spacing have been undertaken in Kenya; although it is widely grown and used in multiple ways in many rural areas. The study sought to determine the interaction between spacing, provenance and Negarim micro catchment on the growth of *Moringa oleifera* in Kitui County. Specific objectives of the study were to determine the effects of spacing on growth performance of two provenances of *Moringa oleifera;* to determine the effects of Negarim micro catchment on the growth performance of two provenances of *Moringa oleifera* under different spacing; and to determine the survival rate of two provenances of *Moringa oleifera* under different spacing and Negarim micro catchment. A 2 × 2 × 3 Factorial Randomized Complete Block Design was adopted. Spacing levels of 100 cm × 100 cm, 150 cm × 150 cm and 200 cm × 200 cm were considered when designing the field plots. Seedlings were raised in the South Eastern Kenya University Botanical Garden and nursery experiment began with the acquisition of seeds in Machakos and Gede. The experiment was set at the farm of Yumbisye Secondary School. Land preparation included removing of trees, uprooting of stumps, establishment of terraces, ploughing with a tractor, and harrowing to a fine till. Considering the land's gradient, suitable experimental sites were identified and three equal blocks created; where every band on the terrace served as an experimental block. The plots were positioned along the contour, and the ultimate land preparation was afterwards tailored to the actual experimental unit. Twelve treatment combinations for both experimental and control plots were generated, randomized within the plot and replicated thrice to 36 experimental units. Data was collected on a monthly basis for a period of 16 months (January 2018/April 2019). Plant height measurements was taken from the stem base to the terminal bud leaf using a graduated rule, root collar diameter measurements were taken at the soil level using Vernier caliper while branch development on the plant and surviving plants determined through manual counting. The data was cleaned, averaged and analyzed using GenStat Release 14.1 for Windows based on the objectives of the research. Gede provenance under Negarim micro catchment, mean plant height was 108.8 cm, mean root collar diameter was 5.5 cm, mean number of branches was 14, and mean seedling survival rate was 66 %. Control treatments mean plant height was 160.2 cm, mean root collar diameter was 7.3 cm, mean number of branches was 18, and mean survival rate was 74 %. The Machakos provenance's results under Negarim Micro Catchment revealed that mean plant height was 152.0 cm, mean root collar diameter was 5.5 cm, mean number of branches was 15, and mean seedling survival rate was 60 %. Control treatments for Machakos provenance reached a mean height of 117.7 cm, mean root collar diameter of 5.3 cm, a mean of 15 branches, and a mean survival rate of 65 %. Provenance and Negarim micro catchment had a significant effect on survivability ($p \leq 0.05$), height ($p \leq 0.05$), and branches development ($p \leq 0.05$). The significant differences of plants under Negarim Micro Catchment were because the catchment provided more moisture advantages to plants than those that were under no Negarim micro catchment. Spacing level of 150 cm × 150 cm under Negarim micro catchment as a suitable water harvesting technique can be recommended for inclusion in tree cultivation systems in the area and other places with similar climatic conditions in enhancing the growth and survival traits of *Moringa oleifera*.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Globally, Arid and Semi-Arid Lands (ASALs) cover 61 million square kilometres; about 46% of the earth's surface (Prăvălie, 2016). These conditions cover about 37% of Africa, 33% of Asia, 16% of Australia and 14% of the Americas (Dobie, 2001). The world's poorest people, living in 110 different nations, make up the roughly 1.7 billion individuals that inhabit this ecosystem (Dobie, 2001). Around 57.6 million hectares of land - representing 84%, of Kenya's total land area lies in ASALs (Luvanda, 2016). Since water is the fundamental constraint for plant biomass production, arid areas are considered by characteristics like fundamentally dry soils, irregular rainfall, and long dry seasons, which together expose these areas to a higher susceptibility level (Ali *et al*. 2010). Such regions' high temperatures and below-average rainfall place significant restrictions on anthropogenic activities like crop agriculture; limiting the numbers animals and plants population that can establish and survive (Ludwig & Asseng, 2006). Effects of climate change will amplify these challenges as it is expected that rain in some areas will become more variable and less intense (Liu *et al*. 2010). Therefore, it is anticipated that the borders of settlements and ecosystems that border these ASALs will be greatly disturbed (Manh *et al*. 2005; Ludwig & Asseng, 2006). In areas where aridity is increasing, cases of famine due to crop failure and ecosystem failure leading to species extinction will be experienced (Parmesan, 2006). However, in order to increase water supply and agricultural production in ASALs, it is necessary to adopt and use methods for gathering and storing rainwater (Muriu-Ng'ang'a *et al*. 2017).

The human population is growing, and land is becoming a scarcer resource. Due to this, people have been compelled to move into semi-arid areas and use marginal lands for agronomical activities (Anschütz *et al*. 2003). However, the shortage of water, high runoff rates and high rates evapotranspiration limit these agricultural activities (CASL, 2006). This suggests that if any sustainable agriculture is to be practiced in these areas, harvesting and conservation of rainwater is necessary (Heluf & Yohannes, 2002). Ensuring proper plant establishment and growth in these regions, effective ways of harvesting and managing water must be developed and put to practice in order to make the most of the available water. Small-scale farmers' lives can be enhanced by implementing the most effective and integrated production methods under stormwater drainage management techniques (Ibraimo and Munguambe, 2007). These techniques include water harvesting practices, irrigation, soil and water conservation (Molden *et al*. 2010).

Moringa oleifera is among the several beneficial and nutritious plants in the world (Mubvuma, 2013). A medium-sized tree, it does well in semi-arid and tropical climates (Igwilo *et al*. 2013), and it is experiencing a gradually increase in the amount being harvested (Khan *et al*. 2013). It thrives well in soils that are well moist and have enough nutrients. However, it can endure harsh climatic conditions that are characterized by high temperatures, low nutrient and moisture soils; conditions that doesn't favor proper plant development (Radovich, 2009). Humans have traditionally used the entire tree (plant) and have consumed it in a variety of ways. In addition to its medical benefits, it can be used as animal feed and supplement, biogas production, a water purifier, bio-pesticide and as a domestic cleaning agent (Igwilo *et al*. 2013). To cater for the supply demands for its products, more acreage is now being used for its farming. However, under normal farming systems, increased *Moringa oleifera* cultivation will take up the resources and space intended for the cultivation of food crops. In some areas, *Moringa oleifera* is grown on a large scale, but very minimal attention is given to its agronomic requirement that can ensure maximum output (Eze *et al*, 2012). It is mostly grown along the edges of farms or in intercropping systems with other food crops. In many cases, it is inferred that leaving aside farms specifically for the cultivation of medicinal trees to ensure that it meets its demand is costly, difficult, and may have an environmental impact (Amaglo *et al*. 2006).

Planting density has been identified as critical management practices that affect biomass yield and leaf quality of plants like *Moringa oleifera* Gadzirayi, *et al*. 2013). Thus, in the production of *Moringa oleifera* would require that among other factors, the spacing for cultivation is given attention (Amaglo *et al.* 2006). It therefore, becomes important to conduct study on the growing characteristics of *Moringa oleifera*, a plant with great medicinal and nutritional value that have a great potential to benefit people, especially those who suffer from poor health problems due to malnutrition and poverty, children and even nursing mothers.

1.2 Problem Statement

Since the natural resource demand like land has been rising due to the population boom, people have been forced to start relocating to previously unexploited arid and semi-arid lands (Kiragu *et* *al*. 2015). These lands are characterized by harsh climatic conditions as a result of erratic and sparse rainfall, low soil water retention capabilities and high temperatures that promote evaporation. The high prevalence of poverty rates is caused by the harsh natural conditions that result in poor agricultural production (CASL, 2006). As a result of the excessive exploitation of the resources available, environmental degradation is inevitable (Vohland and Barry, 2008).

Tackling these issues requires introducing high-value plants and trees that are effectively adapted to thrive in such extreme climates through climate-smart crop cultivation. This is only possible with the application of the proper agronomic requirement, such as spacing between the plants, the cultivation of the most suited provenance, and the use of the proper water collection method, such as Negarim micro catchment (Reddy and Reddy, 2016). This technique was chosen as it is mainly used for growing trees in ASALs, is the most appropriate method of planting trees on small scale basis and the units are fairly easy to construct and aids in soil conservation.

Moringa oleifera has recently gained prominence because of its numerous uses and value as a source of revenue for a substantial population in rural areas. The world's underprivileged populations place a premium on more research that aims to guarantee full utilization and serve as a source of income (Reyes Sánchez *et al*. 2006; Anwar *et al*. 2007 and Pontual *et al*. 2012). To accomplish this, there is an urgent need for conducting studies that will facilitate its effective growth and survival of the seedlings. Further, it appears that rather than focusing on *Moringa oleifera's* agronomy as a farmed agricultural crop, many studies from previous researches like those of Mendieta-Araica (2011); Hamz and Azmarch (2017) and Sahay *et al.* (2017) appear to be more interested in its nutritional and therapeutic benefits. Even though it is widely produced and utilized in a variety of ways in rural areas, there have only been a limited number of researches on its provenance trials, usage of micro catchments, and various spacing in Kenya. Therefore, this research study sought to determine how Negarim micro catchment and spacing affects growth parameters and survival rate of two provenances of *Moringa oleirefa* in arid areas.

1.3 Objectives of the Study

1.3.1 General Objective

This study's main goal was to determine the best agronomic conditions for improved productivity of two provenances of *Moringa oleifera* in the Arid and Semi-Arid Lands of Kitui County.

1.3.2 Specific Objectives

1. To determine the effects of spacing on growth performance (height, branch development and root collar diameter) of two provenances of *Moringa oleifera.*
2. To determine the effects of Negarim micro catchment on the growth performance (height, branch development and root collar diameter) of two provenances of *Moringa oleifera* under different spacing.
3. To determine the survival rate of two provenances of *Moringa oleifera* under different spacing and Negarim micro catchment.

1.4 Hypothesis of the Study

H_{01}: Plant spacing has no significant effect on average growth performance (height, branch development and root collar diameter) of two provenances of *Moringa oleifera.*

H_{02}: Negarim micro catchment has no significant effect the growth performance (height, branch development and root collar diameter) of two provenances of *Moringa oleifera* under different plant spacing.

H_{03}: The interaction between spacing and Negarim micro catchment has no significant effect on the survivability of two provenances of *Moringa oleifera.*

1.5 Significance of the Study

Implementation of this study benefits numerous parties. First, it provides both local farmers and agricultural extension officers the necessary knowledge in establishment of the ideal conditions for growth of *Moringa oleifera*; this will result in increasing production levels of its products, and ultimately higher earnings and better living conditions for farmers. It will assist those who live in dry regions in developing techniques to increase production of *Moringa oleifera*, increase the dependability of rain-fed agriculture, and increase tree productivity by cultivating *Moringa oleifera* or other species of trees with the least amount of water possible. Through the dissemination of information and the development of effective runoff utilization systems, the research supports the goals of environmental preservation and soil erosion management. Non-Governmental Organizations, government parastatals and even government ministries implementing Goal 15 of the Sustainable Development Goals which aim at safeguarding, reinstating, encouraging sustainable utilization of areas with forests, fighting desertification, and discontinuing/inversing land degradation that is linked to loss of biodiversity will also benefit. This will benefit communities dwelling in arid areas, as these activities will increase agricultural production and ultimately their livelihoods. This has led to the forest policy laying more emphasis on the need to move from reforestation of gazetted forests to afforestation of community and farm forests. Lastly, the study created a significant foundation upon which future research in dry regions on climate smart agriculture technologies might be carried out.

1.6 Scope of the Study

The experiment was conducted in Yumbisye area, Kitui Central Sub – County in Kitui County. The choice of study location was purposefully selected as it lies within Kenya's arid and semi-arid lands. The study mainly focused on identifying the impacts of Negarim micro catchment and spacing on growth and survival of two *Moringa oleifera* provenances. Data was collected for a period of 16 months (January 2018/April 2019).

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The *Moringa oleifera* Tree

2.1.1 Taxonomy

Moringa oleifera, sometimes known as the horseradish tree, is one of the 14 species comprising the *Moringaceae* family that is native to India's distant sub-Himalayan regions of Northern India (Muhl, 2010). It has since expanded to Tropical and Sub-tropical regions around the world. The word "*Moringa*" or "*Murunggai,*" which both correspond to the botanical name *Moringa oleifera*, is the source of the tree's common name. However, the tree is known by a variety of names in different regions/countries, but "Moringa tree" is the one that is most frequently used (Abdulhamid & Dau, 2016).

2.1.2 Habitat and Range

Moringa oleifera thrives well on alluvial soil or soils near rivers and streams, and it grows primarily between 0 -1,400 meters above sea level (Sharma *et al*. 2011; Koul & Chase, 2015). It has experienced massive introduction and naturalization in many parts of the world (Foidle *et al.* 2001). This is due to its high adaptability, and it can survive well in the semi – arid and hotter tropical regions with annual rainfall ranging from 250 mm to 1,500 mm. Although it may grow up to 1,200 meters above sea level in some tropical regions and even 2,000 meters above sea level, the most favorable altitude is 600 meters (Price, 2007). Due to its endurance for intense sunlight and warm temperatures, it thrives well in dry lands. Unless the weather is extremely hot, irrigating is seldom needed, but can be done at least once a week (Huda *et al*. 2017) and long waterlogging conditions affect the plant by initiating stem rot (Padilla *et al*. 2012).

Although there is no known higher limit, Muhl (2010) found that it can tolerate temperatures of 48°C for some time. The optimal temperature range for growth is 20 to 30°C. Saint Sauveur & Broin, (2010) reported that the ideal soil types for it to grow are loamy, sandy and sandy – loamy and slightly acidic-alkaline of a pH range of 5 and 9. It was brought to Kenya in the early 20th century by Indian workers working on the Uganda Railway (Mundia, 2003), and according to Mathenge (2015), it is currently largely cultivated in the Northern Region in areas of Garissa, Wajir and Moyale and also in regions of Taita Taveta).

2.1.3 Morphological Characteristics

Moringa oleifera is among the fast-growing trees, with a matured tree averaging from 5 and 12 meters in height and a crown with an umbrella form (Raja, *et al*. 2013). It is evergreen in tropical climates, but deciduous in sub-tropical climate and shedding its leaves in the winter seasons (Muhl *et al*. 2011). Propagation is done through seeds and stem cuttings and the favorite option of propagation, however, differs from nation to nation and even from region to region (Ratshilivha *et al.* 2019). When labour is not a constraint and there are few seeds available, stem cuttings are ideal (Leone *et al*. 2015). If seeds are to be used during propagation, they must be nurtured within nurseries with a light growing medium composed of soil and sand in a 3:1 ratio before being transplanted into the field (Mubvuma *et al*. 2013). Depending on the pre-treatment procedure used and the growing media, seeds start germinating within the 5^{th} and 30^{th} day after sowing and at 20 days after germination, the seedlings are quite well developed with taproot roots and are ready for transplanting after a month (Adegun & Ayodele, 2015).

Like all other plants, *Moringa oleifera* transplants need sufficient nutrients and humidity for them to thrive well (Foidle *et al*. 2001) and is affected by both internal and external stimuli; which determines its ultimate progress and production. When internal and external climatic factors fall within the most ideal range, efficient growth and production are guaranteed. Waterlogging, which is associated with root decay (Olgun *et al*. 2008; Padilla *et al*. 2012), water scarcity and extreme heat (Bosch & Alegre, 2004), salinity (Munns and Tester, 2008), and poor soils are some of the abiotic elements that affect a plant's growth pattern (Fageria *et al*. 2010). In the first three to four years, *Moringa oleifera* develops quickly in favorable conditions, increasing its height by 1 to 2 meters in a year. Within the first year after planting, Munyanziza and Sarwatt (2003) discovered that in Tanzania, seedlings were able to grow as high as 4.1 meters. On root collar diameter, it was reported by Parrotta (2009) that the largest potential expansion is 75 cm. *Moringa oleifera* develops spirally or alternately arranged leaves, measuring 45 cm long, and are often bi-pinnate and occasionally tri-pinnate. The leaves develop leaflets that are 1.2 cm to 2.0 cm in length and 0.6 cm to 1.0 cm in width, with the pinnae and pinnules that are oppositely positioned. The texture of leaflets is characterized by short, pointy tips, smooth borders, center veins with red streaks, and thin, green hairs that are practically hairless on both sides. Branches have a tiny layer of hair covering them, and they are usually green before turning brown (Ridwan & Witjaksono, 2020).

When *Moringa oleifera* tree matures, its fat, greyish - white, woody, squashy, and cracked skin turns into a coarse bark and the wood has a density of 0.5 to 0.7 g/cm^3, which is light and soft (Parrotta, 2009). Growing seedling develop extremely thin lateral roots that are utilized to absorb water along with a swollen, hairy, white root system with a pungent odor. Plants that have been raised from seeds have a thick, deep taproot that is encircled by a vast network of thick horizontal roots. On the other hand, trees grown from cuttings lack taproots (Roloff *et al*. 2009), with a shallower root structure that is vulnerable to water deficit and windfall (Khonje *et al.* 2022).

After 6 to 8 months, *Moringa oleifera* trees grown from stems or cuttings start fruiting (Roloff *et al*. 2009). Climate of the area where it is planted usually affects the flowering process and the plant develop flowers either all year long or twice a year (Muhl, 2009). The flowers are white to yellow in color, bisexual, scented and grow on thin stalks covered in hair that are arranged in spreading or slack auxiliary pinnacles that range in length from 10 to 25 cm. A flower's hypanthium is roughly 3 mm long and contains five asymmetrical, beautifully patterned, spathulate petals that range in color from yellow to white. The pistil is made up of a single celled ovary and a slender style (Sanchez *et al*. 2006). Flowers are primarily pollinated by insects, especially bees, and occasionally by birds (Parrotta, 2009).

The 20 to 30 cm long *Moringa oleifera* fruits are pods whose color progressively changes from green to brown upon maturation, revealing the numerous spherical to three-sided seeds with 3 papery flaps (Muhl *et al*. 2011). At three months, the pods are mature and have developed three sides, with a width of 2.0 to 2.5 cm, and nine longitudinal ridges containing with about 26 seeds each. Fruit yields are low during the first 2 years, but gradually increase in the third year to a peak of between 600 to 1600 fruits annually. The fully developed dehiscent pods can remain affixed to the tree for a few months while releasing their seeds, which are often dispersed by water and wind rather than by seed-eating animals. Mature seeds have a diameter of about 1 cm with a covering of three whitish paper-like wings at the angles, and weigh between 3,000 and 9,000 seeds per kilogram; depending on the variety (Parrotta, 2009).

2.1.4 Pests and Diseases

Moringa oleifera is not significantly impacted by diseases or pests (Raja *et al*. 2016), unless during some special circumstances, such as epidemics (Palada & Chang, 2003). However, the three insects that are recognized to be the most major pests include caterpillars, grasshoppers and crickets. Their effects are revealed when they gnaw or nibble on different plant parts, they destroy the buds, pods, shoots, flowers and leaves. When sap-sucking red spider mite infest the *Moringa oleifera* tree, they disrupt the plants' sap flow system (Gadzirayi *et al*. 2013). *Eupterote mollifera* and *Diplodia spp*. that are associated with root rot, budworm, green leaf caterpillar, and bark-eating caterpillar were reported to be affecting the tree in India and the affected plants shows signs of defoliation. Managing these caterpillars is by spraying fish oil and / or resin soap. Diplodia root rot develops in water-logging conditions, which causes the plants to severely wilt to death (Palada & Chang, 2003).

Flint (2018) noted that in organic farming, it's crucial to keep the space of the trees free of weeds that harbor pests and disease vectors to prevent their spread. It is also important to frequently check young leaves and shoots for signs of effects of pest and fungal infestation to control them before much damage. Sammy (2018) stated that although not effective as inorganic chemicals, spraying the plants with extracts from neem tree leaves or seeds on the damaged plants when infestation symptoms are present decreases the impact and spread of the disease, pest or fungus.

2.1.5 Uses

Edward *et al*. (2014) reported that *Moringa oleifera* is a versatile tree, used both important in industrial and domestic setups. Its seeds, which have been dried and ground, are used as a water coagulant due to their ability to set germs and debris in the water at the containers' bottom; allowing for the decantation of the cleaned water (Orwa *et al*. 2009; Addo, 2011). In conventional medicine, it is a "miracle tree" due to its extensive medical benefits in curing a wide range of diseases (Anwar *et al.* 2007). It fights bacteria and fungi and aids in reducing blood cholesterol (Muhl, 2009), slows and prevents free radical damage of cells due to its antioxidant properties (Siddhuraju and Becker, 2003), and managing various cardiac and digestive problems (Anwar *et al*. 2007; Raja *et al*. 2016).

As food for human consumption, *Moringa oleifera* has several nutritive benefits (Fuglie, 2001). The leaves provide a significant source of carotine, protein, phenols, ascorbic acid that adds up as a food preservative, flavonoids, and ions like calcium (Anwar *et al*. 2007) and potassium (Mishra *et al*. 2012). Without losing its nutritional values, the leaves can be consumed in various forms that include fresh farm leaves, adding to cooked dishes, dried and processed into powder for longer shelf life (Anwar *et al.* 2007). Table 2.1 provides an overview of the nutritional content of 100 grams of fresh *Moringa oleifera* leaves that can be eaten.

Table 2.1: Nutrients levels of fresh *Moringa oleifera* leaves in 100g of leaves

Nutrient	Value
Energy	92 Kcal
Phosphorus	70 mg
Carbohydrates	12.5 grams
Proteins	6.7 grams
Fats	1.7 grams
β - carotene	6780 micro grams
Fiber	0.9 grams
Vitamin C	220 mg
Iron	0.85 mg
Calcium	440 mg

(Source: Muhl, 2010)

Moringa oleifera has a variety of ecological advantages, such as preventing soil erosion in regions where strong winds and prolonged droughts coexist; leaving soils vulnerable to erosive agents (Orwa *et al*. 2009). The partial shading conditions provided by the tree whenever it is intercropped are crucial for shielding nearby plants from the impacts of direct sunshine. In Kenya, Tanzania, Nigeria and India it is widely integrated within hedge and live fencing as a form of protection from high winds, a fence around homesteads, or in supporting lianas (Mridha, 2015). Its leaves are a significant source of mulching (Orwa *et al*. 2009) and press cake from the extraction of moringa seed oil can be added to the soil as a fertilizer or conditioning the soil (Orwa *et al*. 2009). Additionally, the tree is sometimes grown for beautification purposes (Popoola & Obembe, 2013).

In animal husbandry, *Moringa oleifera* leaves are added to various animals' diets. As a result of feeding livestock moringa-based diets, Sarwatt *et al*. (2004) and Reyes-Sánchez *et al*. (2009) have found improved milk output and growth in livestock (Reyes-Sánchez, 2006). Its supplements in poultry production enhances production of egg (Kakengi *et al.* 2007). Furthermore, *Moringa oleifera* seeds are pressed to extract Moringa Seed Oil, an odorless, sugary, colorless and non-drying oil used in sensitive lubrication for machinery like watches, cosmetics industry, food industry (Saint Sauveur & Broin, 2010) and bio diesel production (Rashid *et al*. 2008) through trans-esterification (Poet, 2006).

2.1.6 Farming of *Moringa oleifera*

Kiragu *et al*. (2015) noted that *Moringa oleifera* receives little to no attention regarding its agricultural requirement to maintain optimal productivity and soil usage in areas where it is cultivated on a large scale. The plant is sparsely distributed due to its lack of capacity to completely recover following a significant disturbance; such as a diseases and pests, overexploitation, or even being nibbled on by foraging animals. Nevertheless, ongoing cultivation has allowed many people in middle income countries to benefit from its nutritional and financial benefits because of its capacity to thrive effectively and quickly in harsh climatic conditions (Raja *et al*. 2013). *Moringa oleifera* is generally planted by local farmers on a small-scale basis in their agroforestry schemes, whose guarantee for sustainable development is in their ability to continue its supply as human and animal nutritional source and as a revenue stream over years. The desire for its products is therefore expected to only be satisfied if its cultivation practices are centered on improved agricultural measures.

Adegun & Ayodele (2015) reported that in agriculture, plant population determines its productivity, which is typically influenced by space between the plants and planting design which in turn affect growing characteristics, yielding capacity, and the yield qualities. Adegun & Ayodele (2017) reported that so as to maximize plant growth, development and yield per unit area of land, stand density and planting patterns are utilized. As a result, plants should be placed at a spacing that will result in the highest possible economic yields of crops. Crops' responses to the availability of physical variables surrounding them and the changes brought about when the availability of one component is insufficient to meet the combined needs of the related crops are referred to as spacing effects. As a result of competition for space and sunlight, crowded plants would naturally grow higher, making this rivalry visible. Closer spacing would induce vertical growth by reducing the amount of space available surrounding each plant for lateral expansion.

The level of *Moringa oleifera* plant spacing in the farm is determined by the scale of farming in practice and environmental conditions of the area (Rajangam *et al.* 2001). In order to ensure ease field maintenance and operations in a semi-intensive agriculture, Saint Sauveur & Broin (2010) advised the use a spacing to be done in appropriately spaced lines of 10 cm × 20 cm and 15 cm × 15 cm. An alternative approach was suggested by Pérez-Rivera *et al*. (2021) of establishing lines that are 45 cm apart from one another and seeding at every 10 cm to 20 cm along them, or using lines that are 30 cm apart from one another. In normal cultivation practices, 50 centimetres to 100 centimetres was found to be ideal when interplanted in agroforestry lines. To keep the intercrops from getting too much shade, the trees need to be planted in rows that are between 200 and 400 cm apart and face east to west. According to Foidle *et al*. (2001), there is a likelihood of having variable outputs when growing *Moringa oleifera* as a single crop using different spacing because of variations in the soil characteristics, amount of rainfall received, capacity of the soil to keep humidity and temperatures experienced in the area.

2.2 Techniques for Water Harvesting

Arid areas are characterized by rainfall that is both uneven and unpredictable, and the received amount is mostly lost through evaporation and runoff due to lack of vegetation cover in large parts of these areas. Due to these reasons, various techniques for harvesting water have been developed over time for collecting and utilizing runoff (Laura, 2004). Water sustains life by facilitating steady a steady environment that supports development in agricultural, social and economic spheres. For a long time, dry areas have used several water harvesting practices to reduce the effects of drought by meaningfully increasing the amount of water available for domestic water needs, enabling proper management of the environmental by protecting sensitive habitats, stabilizing crop yields through land irrigation, and restoring degraded lands (Rainwater Harvesting, 2006). Activities of harvesting water, reducing and capturing runoff increases the average amount of water that is available for various uses, including agricultural activities, domestic and even livestock production. This is ensured by bridging / connecting droughts and dry seasons by storing and availing enough water that meets these demands (Studer & Liniger, 2013). Conservation of water includes all actions that are aimed at properly managing both crops and soil characteristics to improve the soil profile's capacity in rainwater storage (Rana, 2007). This can be achieved by collecting raindrops where they land, and at times, moving of the runoff to a storage area (Assefa, 2021).

In arid areas, water is the main production factor that prevents substantial agricultural activities. However, agricultural lands loose a significant amount of water through surface runoff (Geremu *et al*. 2016). Because of the soil's poor ability to retain moisture - rendering the plants' inefficient use of it, and high rates of evaporation, agricultural activities are greatly constrained. In arid areas, it is necessary to provide insufficient rainfall in the form of soil moisture that may be absorbed by plants for their growth (Walle & Belayneh, 2014). In order to tackle these water scarcities, water harvesting is necessary, however, it is important to choose the best methods that capture most of the rainfall in received in an area (Ibraimo & Munguambe, 2007). Water harvesting schemes are able to increase crop and plant varieties and agricultural productivity while decreasing levels of soil erosion and rehabilitating degraded lands. Water harvesting and storage is important to ensure survival of transplanted seedlings, encourage proper root development and spread (Ali & Yazar, 2007).

For many years, a number of developments have been made with the goal of increasing volumes of water that is available for farming activities through accumulation of excess runoff (Gebreyess & Amare, 2019). These revolutions help recharge subsurface aquifers and enables crop irrigation schemes to be fruitful in semi-arid lands, thereby lessening pressures on such insufficient resources. Techniques for water harvesting are now being used in improving availability of clean and safe water that can also be used in agricultural practices (Rani, 2023). This has helped to reverse the speed of environmental degradation by encouraging tree planting practices, recharge of aquifers, mitigating effects of poverty within a population and encouraging proper management of water as a resource and also mitigating the effects of floods and droughts when excess water is stored for future use (TWDB, 2006). To effectively develop and utilize a specific water harvesting technique, it becomes important to understand rainfall dynamics of the specific area. This is important in determining the most appropriate and efficient method to be adopted as water harvesting techniques are typically dependent on unpredictable and restricted rainfall (Qadir *et al*. 2007). Important rainfall dynamics to be considered are the probability of raining, instances when received rainfall will surpass that inception rainfall, recurrence of the lowest and highest monthly rainfall amounts, presence of storms and average rainfall over a period of time; monthly and yearly (Prinz & Singh, 2000). To realize productive farming in dry lands, it is important to realize the soils' ability to successfully hold and store water received in any season before absorbed by plants for growth (Demoz, 2016).

Depending on the amount of rainfall experienced in an area, techniques for conserving water are broadly divided into main categories; in-situ water conservation systems and ex-situ water conservation systems. In-situ water conservation systems are usually adopted in regions where the soils' profile has the capacity of storing adequate water that meets specific crop requirements, after all forms of losses like runoff (Demoz, 2016). Some areas however, have thin soils and the retained water may not be enough. In these situations, it's crucial to enhance rates of water infiltration, while lowering rates of surface runoff and ex- situ water conservation systems are frequently used in these regions. This system utilizes water collected in a higher area modified to increase runoff of the received precipitation and direct it to a lower area where it is stored for plants grown (Rana, 2007).

2.2.1 Micro Catchment Systems

These are systems designed to basically capture rainfall and surface runoff in order to increase moisture content in the soil and ultimately plant cover in an area (Ali & Yazar, 2007). Their design basically has two sections, the catchment zone that is designed to generate and direct runoff; and the cultivation zone that is designed at the lower end of the catchment zone for holding the received runoff for the plants established there (Mbilinyi *et al*. 2005). The catchment area's length typically measures from 1 to 30 cm, with a ratio of the catchment zone to cultivation zone that is either 3:1 or 1:1. Semi-circular bunds, contour bunds and Negarim micro catchment are a few examples of micro catchments that are commonly used in arid lands (Ibraimo & Munguambe, 2007).

Micro catchment systems, as opposed to irrigation systems, have additional benefits. It is easy to construct, don't need much money or labor to build because they can be quickly built and maintained with local labor and resources. Because there are no instances of pumping and transfer of water from remote sources, there are few incidents of soil pollution; the runoff accumulated has a minimal salt concentration; reducing chances of soil salinization. Sufficient runoff is gathered in the cultivated areas to meet the needs of the crop; the area is typically calculated or approximated when designing the unit (Matthew & Bainbridge, 2000).

2.2.2 Negarim micro catchment

This comprises of units that are isolated from one another by a wall that is continuously constructed within a predetermined region. This system has its origin in the southern parts of Tunisia, before being improved in the Negev Desert of Israel; which has research farms with extensive and well-established structures (Ayanshola & Dauda, 2019). This desert receives between 100 millimeters to 150 millimeters of rainfall in a year, which cannot sustain plant growth. These structures further include soil treatment approaches intended to boost rainfall water to drain in a storage section that is planted with trees (Moges, 2004). The goal is to conserve collected precipitation and runoff while optimizing soil storage characteristics (Geremu *et al*. 2016). According to Muriu-Ng'ang'a *et al*. (2017), Negarim micro catchment systems in Kenya are widely adopted in parts of Meru and Kitui Counties and around Thika in Kiambu County.

Two major components make up a Negarim Micro Catchment unit; the cultivation zone and the catchment zone, that are established in a specific ratio. In order to capture rainwater and direct it to the cultivation zone, where crops are established, the catchment zone is purposefully kept uncultivated (Ayanshola & Dauda, 2019). The collected water is stored at the cultivation zone, where plants are established to ensure the root zone receives maximum moisture. Stones and soil are used in building unit walls (Anschütz *et al*. 2013). The soil that is excavated is typically utilized to form the ridges with a 45^0 sheered square. In the unit there is a hole with a depth of 50 cm. The collected water is concentrated and stored at the square intersection (KEFRI, 2014) as demonstrated in Figure 2.1 below.

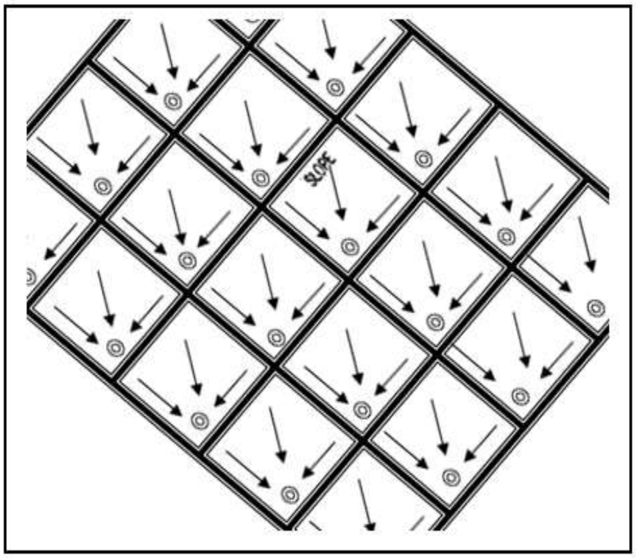
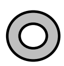
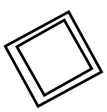


Figure 2.1: Units for Negarim micro catchment

Source: Ibraimo & Munguambe (2007).

Key: ⟶ Direction of slope and runoff flow

 Location of the plant

 Negarim micro catchment unit

Ayanshola & Dauda (2019) suggested the following procedure is adopted in designing of Negarim micro catchment units:

The amount collected and additional water needed by the plant are what determines the catchment zone and cultivation area (zone) (C:CA) ratio. i.e.

$$Collected\ water\ (CW) = Additional\ required\ water \quad (1)$$

Runoff from precipitation that fell in a location is what produces the water that is retrieved from the catchment area. When the Design Rainfall (DR) is multiplied by a coefficient of the rainfall (CR), the quantity of runoff collected (RC) is determined. Since a much lesser portion of the runoff is actually used, there is need to use of an efficiency factor (EF). The volume of water that was harvested in this instance is shown as:

$$CW = C \times DR \times CR \times EF \quad (2)$$

The total water demands (TWD) of the crop, which are the overall demands of water less the estimated design precipitation (EDP), are multiplied by the area of CA, resulting in the required water (RW), where:

$$EDP = CA\,(TWD - DR) \qquad (3)$$

Since the additional water required has to be equal to the collected water, equations (2) and (3) can be used to obtain the C:CA ratio of the units as represented below.

$$\frac{TWD-DR}{EDP\times CR\times EF} = \frac{C}{A} \qquad (4)$$

Depending on the size of the catchment being used, the infiltration pit can take the shape of a square or a circle. Figure 2.2 illustrates how the Negarim Micro Catchment unit functions.

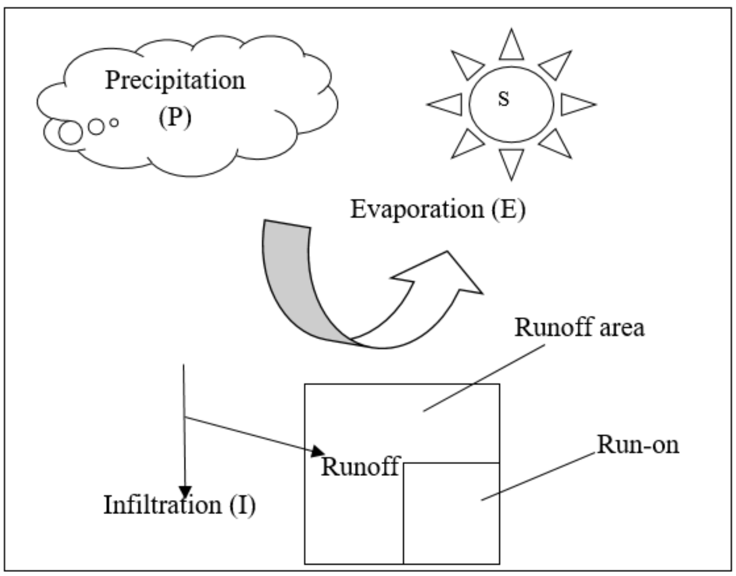


Figure 2.2: **Design and functionality of a Negarim Micro Catchment Unit**

Source: Al-Ali (2012)

Sizes of single units of Negarim micro catchment typically range from 10 to 100 Square meters, depending on the species to be grown (SCTD, 2001). Bund height usually varies, depending on the slope of the site and the extent of the catchment. The Negarim micro catchments' runoff efficacy allows them to concentrate huge volumes of runoff in the CA zone, ensuring plant development (Ali & Yazar, 2007). Ibraimo & Munguambe (2007) reported that on addition to collecting water used for tree growth with insufficient soil moisture content, this system aids in soil conservation in areas where it has been adopted. On the contrary, it is challenging to automate and maneuver between rows of trees, making it only suitable for small-scale application.

2.3 Arid and Semi-Arid lands

About 84% of Kenya's land area is covered by ASALs (Barrow & Mogaka, 2007). Initially, these areas have been supporting a comparatively small human population as a result of low rainfall volumes received and limited agricultural productivity (Tang & Zheng, 2019). Many countries of the world are experiencing rapid population increase in these areas due to internal migration from high-potential area and expansion of existing population, many of these regions have recently seen a rapid increase in the population (Oucho, 2020). According to Kenya Republic (2005), in 2005, a population of 9.9 million individuals, were living in the ASALs. Due to this, ecological degradation has increased in regions that border high-potential zones (Barrow & Mogaka, 2007).

These areas experience about 700 millimeters of rainfall in a year and are characterized by recurring droughts and different forms of soil types that support different species of plants. Basically, inter-annual rainfall does frequently fluctuate at a rate of 50 % to 100 % and 20 % to 50 % in the ASALs respectively (CASL, 2006). The eastern Kenya's tropical continental semi-desert climate experiences annual rainfall that are less than 500 millimeters and a temperature of between 22^0C to 27^0C annually; with a wide daily 11^0C temperature range. The average yearly rainfall is extremely variable, with typically clear skies (Obiero & Onyando, 2013). Additionally, the little rain that these areas receive may become less available due to the evaporation rates that are high; resulting to the long-term establishment of numerous systems of collecting and utilizing water (Laura, 2004).

Techniques of harvesting water must be taken into account in order to improve and maintain water access and needs in these areas (Ibraimo & Munguambe, 2007). Going by the predictions about climate change, droughts in these regions would likely vary in size and intensity; while becoming more frequent and severe. Drought increases occurrences of environmental degradation, while decreasing the amount of feed available to livestock, and eventually increasing sufferings. In some areas, rainfall has been less abundant, and the 1999 – 2000 and 2005 – 2006 drought seasons both saw an elevation in the intensity of the drought (IUCN, 2006). In light of these tough climatic conditions, it becomes crucial to effectively use the limited resources, especially the received rainfall. Surface runoff can be harvested to provide water because not all rainfall can be captured. Another strategy is to encourage the soil's absorption capacity of the rainwater, while reducing its rate of escape (Biazin, 2012). It is typically unlikely for areas with an annual rainfall of less than 100 mm to offer sufficient moisture for plant growth and continuous forest cover development. However, if 100 millimeters of rain are gathered and concentrated in an area that is a quarter of the region's overall size, a 400-millimeter water column can be reached, sufficient to sustain growth of plants in such areas (Beckers *et al.* 2013). While it is not always dependable in ASALs, rain continues to be the sole accessible, low-cost supply of water that may be used for agriculture in many places. Due to the lack of alternatives in these dry regions, better and more trustworthy methods of utilizing rainwater have been adopted in order to assure expanded and stable food production to meet the needs of the growing population. Therefore, it becomes important to make sure that agricultural activities properly capture and utilize runoff (Koohafkan & Stewart 2008).

These regions' water supplies are scarce, temporary, and mainly salty. Most families rely on raising livestock and growing crops. For a long time, pastoralism has traditionally been the only sustainable source of income because rain-fed agriculture is dangerous because of the likelihood of crop failures at a frequency of twice or more out of every five years. Despite this, the primary source of livelihood in these communities has now shifted to crop agriculture (Nabati *et al*. 2020). While only irrigation, opportunistic rainfall or opportunistic water sources are used for agricultural production, pastoralism depends on ecosystem services like water, forage, and pastures. Ecological limitations experienced such as irregular rainfall with lengthy dry spells, intense rainfall that results in powerful storms, high rates of runoff, high evapotranspiration rates, and depleted soil nutrients in these regions prevent them from engaging in typical agricultural operations (Barrow & Mogaka, 2007). Soils in these areas tend to be composed of mainly sands that are coarse grained and fundamentally poor in organic matter, making them vulnerable agents of erosion. As a result of these, the soils have an extremely brittle natural base and crops planted even during the season of typical rainfall are likely to immediately experience the consequences of drought and moisture stresses (Geremu *et al.* 2016).

2.4 Conceptual Framework

Inherent and induced deficiencies of major soil nutrients as well as low soil moisture (Kathuli & Itabari, 2015) have contributed to the ASALs of Eastern Kenya's high temperatures and low, irregular rainfall, which have reduced agricultural productivity and contributed to the region's food insecurity (Jaetzold *et al*. 2007). Non-governmental organizations (NGO) and researchers have created a number of water harvesting technology adaptations for semi-arid regions (Campbell *et al.* 2014). In order to ensure soil maintenance, control soil erosion, promote water preservation, increase harvests, increase nutrient use efficiency and agronomic efficiency, reduce runoff by increasing infiltration through creating and enhancing depressional water storage, and increase soil biological activities, promoted techniques, such as the use of Negarim micro catchment, have been found to minimize the effects of droughts (Getare *et al*. 2021). The use of the Negarim micro catchment technology in ASALs would lead to improved soil fertility and moisture retention, higher agricultural tree crop output, and a decrease in poverty and food security, as shown in Figure 2.3.

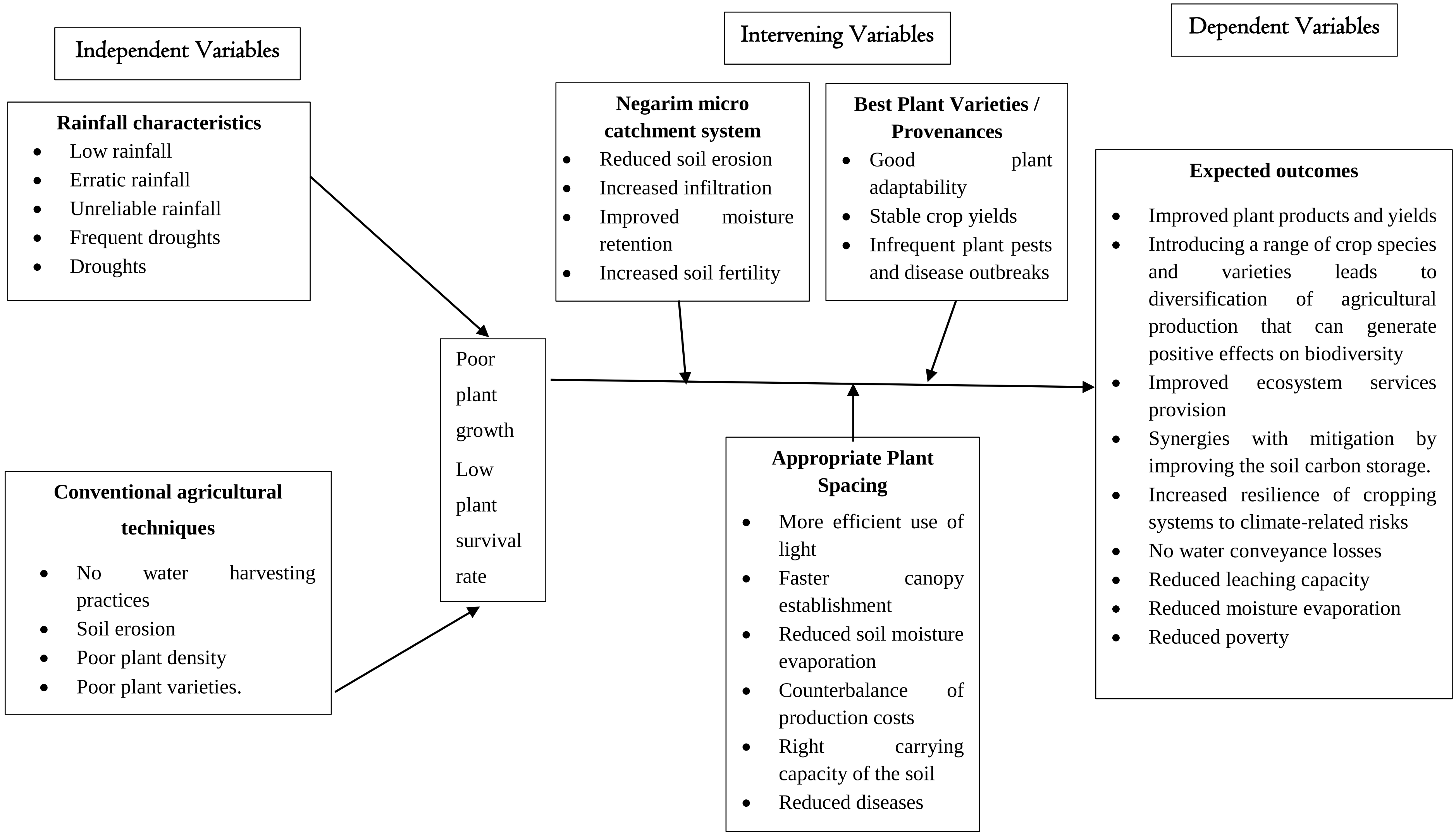


Figure 2.3: Conceptual Framework Source: Modified from the Sustainable Livelihood Framework, IPCC, (2007) and Nelson *et al*. (2010).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Study Area

3.1.1 Size and Location of Study Area

This experiment was carried out at Yumbisye Secondary School farm which lies at latitude of 38.01057 East and longitude of 1.39988 South in Kitui Central Sub - County, Kitui County. The County is roughly 160 kilometres east of Nairobi City and lies between latitudes 0°10 South and 30° South and longitudes 37°50 East and 39°0 East. It is the sixth-largest county among the total counties in Kenya, with a total area of 30,496.51 square kilometres. It shares borders with seven other counties: Tana River County to the east and south-east, Taita Taveta County to the south, Makueni and Machakos Counties to the west, Meru and Tharaka-Nithi Counties to the north, and on the northern side is Embu County (GoK, 2013). The county features forty wards and eight sub-counties (IEBC Kitui Office, 2013). The wards of Kitui Central Sub-County are indicated below in Figure 3.1

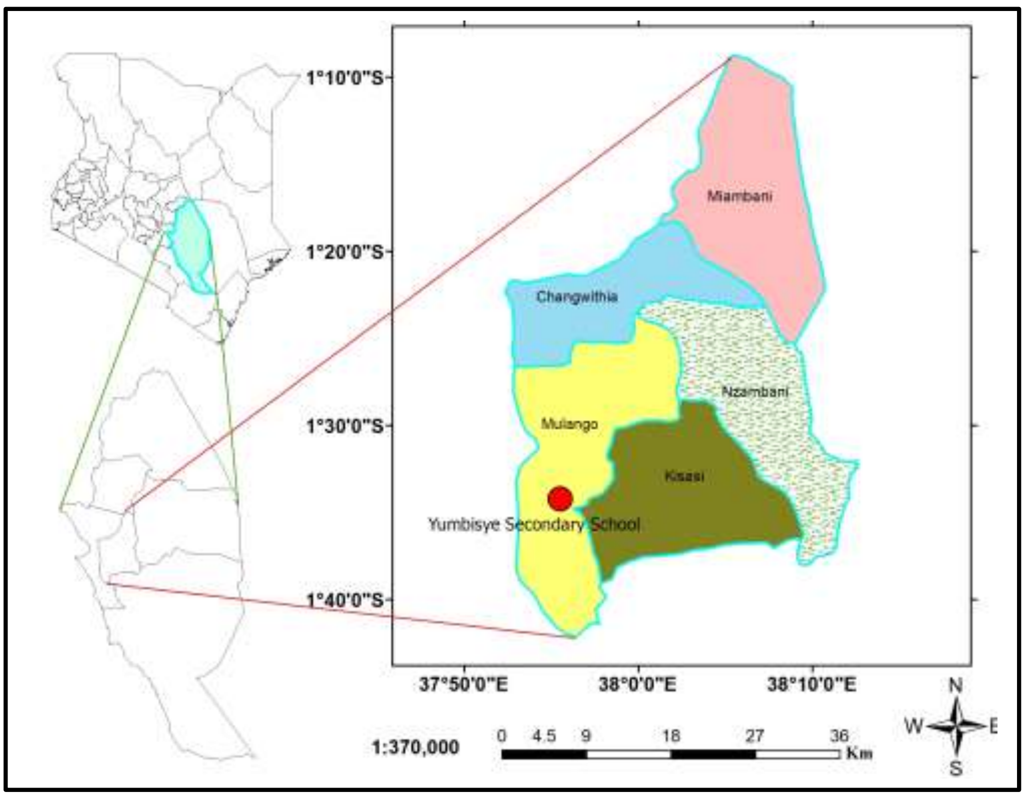


Figure 3.1: The map of Kitui Central Sub - County showing the Study Area

Source: ILRIS GIS Database

3.1.2 Topography

The County's terrain is mostly flat and moderately rising to the east and northeast, with an average elevation of 400 to 1800 meters above the sea level. The Yatta Plateau, which runs from North to South is the County's main physical feature, located on the eastern side of the County and bordered by river Athi and river Tiva. The landscape of the farm is generally flat and gently slopes to the West. The soils comprise mainly of sandy soils (Kitui County Climate Information Services Strategic Plan, 2015). The topography around the study area is generally even.

3.1.3 Weather Conditions

The entire Kitui County lies within the ASALs. Long rains are received from the month of March to May, while short rains are received from October to December and are more reliable in agricultural production. Annual rainfall ranges between 250 mm and 1,050 mm that is erratic and unreliable; while the annual average relative humidity is 45 % (Kitui County Climate Information Services Strategic Plan, 2015). The County is mostly dry and hot with temperatures ranging 14°C during the coldest months (July-August) and 34°C during the hottest months (January-March) (County Government of Kitui, 2014).

The specific study site lies within semi – humid to semi – arid climatic conditions, receiving 1000 mm per annum with a 40 % reliability. A general decline of rainfall is being experienced in the main rain season of April/May and a general positive trend for the short rain season of September/December. January – March and June – September are relatively dry months. The mean minimum temperatures range between 22°C to 28°C while the annual mean maximum temperatures range between 28°C to 32°C (ROK, 2010).

3.1.4 Fauna and Flora

Kitui County is home to several animal species due to the vast tracks of uninhabited vegetation that provide a conducive environment for wildlife. The Kora National Reserves and part of the Tsavo East National Park which are habitats for buffaloes, elephants, monkeys, hippos, gazelles, several bird species and crocodiles in Tana River (Kitui County Climate Information Services Strategic Plan, 2015).

The county is habitat to numerous plant species that are used in various ways. There are 15 ungazetted forests and the most common indigenous ones include *Acacia spp.*, *Adansonia digitata*, *Agave sisalana*, *Melia volkensii* and A*loe vera* that have evolved to thrive in such drought-prone environments. Despite the County's various land tenure structures, an estimated 35,592.6 hectares are covered in forests. These forests serve as a source for a wide range of goods, including wood that is used in various activities like curving, building poles and posts, poles, and even timber. Other products include as fuel, herbal remedies, and animal fodder. Among the ecological benefits provided by the forests are the management of soil erosion, and the preservation of water resources. This is crucial for conserving soil and water resource along riverbanks and hillsides as well as improving fertility of the soil. However, there are cases of over utilization of forest resources. Farm forestry is the practice that contributes to the supplementing of these resources by boosting cash flow avenues to the community (Kitui County Climate Information Services Strategic Plan, 2015).

3.1.5 Water Resources and Hydrology

Kitui County is one of the semi-arid counties in Kenya which is faced with serious water scarcity challenges. The frequent droughts experienced have led to a reduction in water supply which has subsequently led to the drying of many of the seasonal rivers (County Government of Kitui, 2014). Seasonal rivers tend to immediately dry up when the rains stop are the main source of surface water. In addition, the County has two permanent rivers that determines its drainage system – Tana River and Athi River that extent to the neighbouring counties (Kitui County Climate Information Services Strategic Plan, 2015). The study site is drained by river Nzeeu that is less than 500 meters, which drains into river Tiva and subsequently to Athi River.

3.1.6 Population

The 2019 Kenya Population and Housing Census data showed that there were 105,991 residents; 52,123 male and 53,863 female in Kitui Central Sub - County had (KNBS, 2019).

3.1.7 Social and Economic Aspects

Residents around Yumbisye area participate in a variety of activities to sustain their way of life. Cattle farming - for both meat and milk, and rearing of chicken, rabbits and honey bee is undertaken. Food crops, fruits and vegetables farming for both domestic consumption and for sale is done. Sisal and cotton farming are undertaken on some percentage, specifically for commercial purposes. Other commercial activities include mining, tourism, trade and industry are also undertaken (Kitui County Climate Information Services Strategic Plan, 2015).

3.2 Research Design

A 2 × 2 × 3 Factorial Randomized Complete Block Design was used for the experiment. Two levels of *Moringa oleifera* provenances; Machakos and Gede, two levels of water harvesting; under Negarim micro catchment, the control pits and three levels of tree spacing; 100 cm × 100 cm, 150 cm × 150 cm, and 200 cm × 200 cm. The treatments were merged into 12, randomized and replicated three times to 36 experimental units. Seeds were initially planted and raised in a nursery before being transferred to the experimental plots for measurements to be taken.

3.2.1 The Nursery Experimental Design

The seedlings were raised in the South Eastern Kenya University Botanical Garden, located some 30 kilometres from the research site. Nursery experiment began with the acquisition of seeds for two provenances of *Moringa oleifera* - in Machakos and Gede areas. Cleaning of the seeds was done before sorting them out on the basis of their size and color. Those that were larger than 1 centimetre in diameter with grey/white color were selected to be planted. The nursery experimental layout consisted of 36 randomly set plots, where one provenance had 18 plots, and each plot had 20 polythene pots; with a diameter of 12 centimetres and 18 centimetres height. The polythene pots were arranged 15 centimetres from each column and row. In a single day, a seed of both provenances was sown in each pot at a depth of 2 cm from the soil's surface.

Germination was tracked daily up for a period of 28 days after planting, when no more germination was anticipated as per Bayé-Niwah & Mapongmetsem, (2014). Watering was done on daily basis and was discontinued 1 day before the transplanting exercise (28th day) to prevent the wet soil from disintegrating in case the pots break during transit to the field. The plots were maintained during translocation to ensure that there is no mix-up. The actual nursery plots arrangement was represented in Figure 3.2 below.

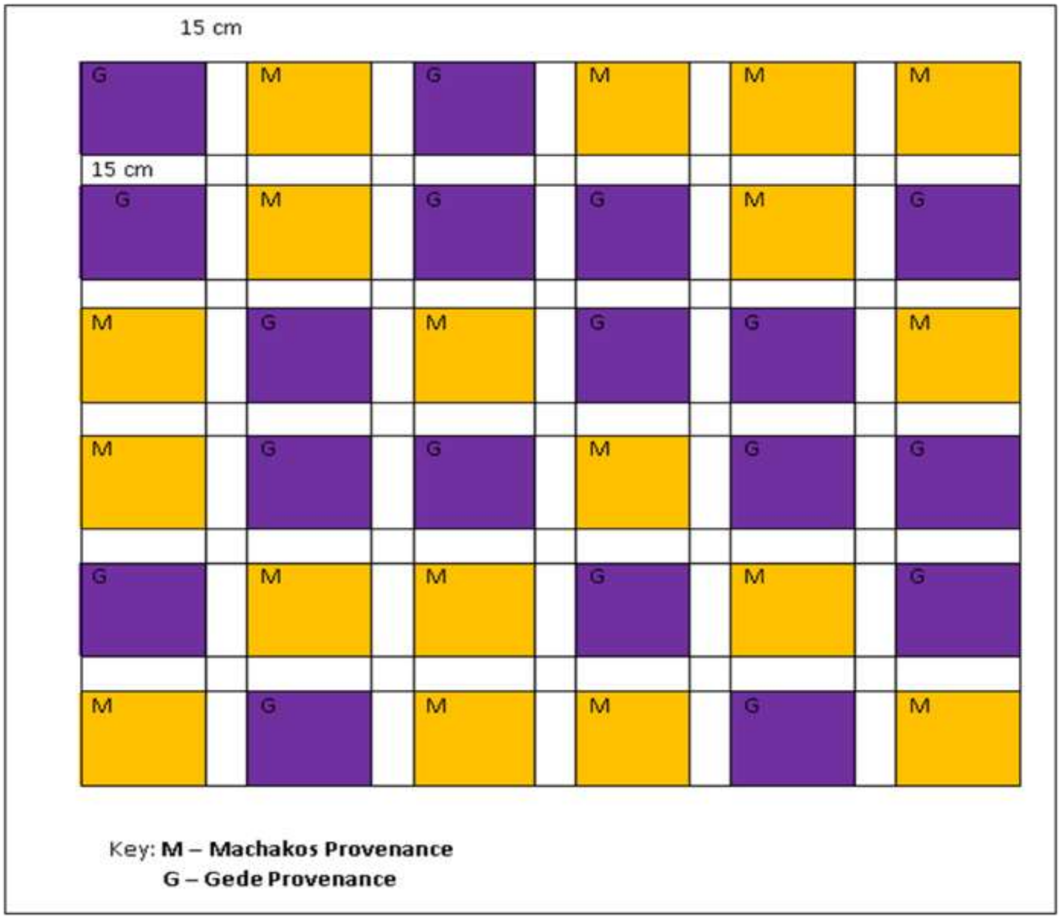


Figure 3.2: Nursery Experimental Layout at South Eastern Kenya University

Source: Author, (2022)

3.2.2 Field Experimental Layout

Field plots were located at Yumbisye Secondary School farm, Kitui Central Sub - County. Historically, the field was virgin and had not been farmed recently hence land preparation involved land clearing and removal of trees / stumps, digging of terraces across the field, ploughed with a tractor, and harrowed to a finer till. Considering the land's gradient, suitable experimental sites were identified and three equal blocks created; where every band on the terrace served as an experimental block. Each treatment was randomly assigned to one of the three blocks, repeated three times, generating 36 experimental units. The plots were placed along the contour, and the ultimate land preparation was afterwards tailored to the actual experimental unit.

Three levels of plot preparation for plant spacing were taken into account; these were 100 cm × 100 cm, 150 cm × 150 cm and 200 cm × 200 cm, with each plot comprising of 16 plants. Negarim micro catchment was used for the half of the experimental treatments, while traditional planting methods with no catchment were used as control treatments. Bearing in mind the ratio of catchment zone to cultivation zone for plots under catchment, the cultivation zone for each unit were 33 cm × 33 cm, 50 cm × 50 cm, and 67 cm × 67 cm, for 100 cm × 100 cm, 150 cm × 150 cm and 200 cm × 200 cm spacing levels respectively. A 30 cm deep seedling planting hole was made in every unit. The field experimental layout is depicted below in Figure 3.3.

Figure 3.3: Field Experimental Layout at Yumbisye Secondary School

Source: Author, (2022)

3.3 Collection of Data

After transplanting, survivability was observed for 4 weeks before seedlings that did not survive were gapped. Six weeks after the seedlings had been transplanted, four plants were randomly selected in every plot, tagged and were to be observed for root collar diameter expansion, height, branches development and survivability of the seedlings. A graduated rule was used to measure plant height from the base of the stem to the terminal bud leaf. At the soil level, a Vernier caliper was used to measure the root collar diameter expansion, and manual counting was used to determine the plants that are surviving. Throughout the growing phase, the plants' survival rate on the plot was recorded and collection of data was undertaken for a period of 16 months (January 2018/April 2019).

3.4 Data Analysis

After collection, the data underwent cleaning and then averaged. Analysis of data was based on the objectives of the research. For Objective 1, average values of plant height, root collar diameter and branch development of the two provenances of *Moringa oleifera* were compared with spacing values to see if there were any significance differences. For the second objective, average values of plant height, root collar diameter and branch development of the two provenances of *Moringa oleifera* were compared with the effect of Negarim micro catchment to see if there were any significance differences. On Objective 3, the average value survival of the provenances was compared for any significant variations under varying spacing and Negarim micro catchment.

To compare the various treatments, the data was submitted to a three-factor Analysis of Variance (ANOVA) with a 95% confidence level using GenStat Release 14.1 for Windows. ANOVA was the most appropriate method of analysis because it enabled to effectively measure how significant the interaction between the variables of the study. The three-factor ANOVA was used as it enabled the determination of how a response was affected by three factors (independent variables and dependent variables) that had been included in the study. Significant change was then determined at $p = 0.05$ using the F test, and the significant means manually separated. The F - test served as the basis for evaluating hypotheses and making judgments and the p values are used to determine if the null hypothesis accepted or rejected. *P* values below 0.05 indicate strong evidence that there are significant differences, hence, rejecting the null hypothesis. The findings of this research were displayed in graphs and tables before conclusions and suggestions were made.

CHAPTER FOUR

4.0 RESULTS

4.1 Effects of Spacing and Negarim micro catchment on growth of provenances of *Moringa oleifera*

4.1.1 Plant Height Growth

4.1.1.1 Plant Height Growth under No Negarim micro catchment

Under no Negarim micro catchment, it was observed that all of the plants' heights increased steadily during the early phases of growth. As displayed in Figure 4.1, Machakos provenance at 150 cm × 150 cm spacing level achieved the lowest mean increase in height (62.1 cm), whereas Gede provenance at 200 cm × 200 cm spacing level had the greatest mean average height growth (191.2 cm). Under 100 cm × 100 cm spacing level, Gede provenance had the lowest mean (126.8 cm), while Machakos provenance achieved the greatest mean (173.6 cm). Under 150 cm × 150 cm spacing level, the mean was highest for the Gede provenance (162.6 cm) and lowest for the Machakos provenance (62.1 cm). Under 200 cm × 200 cm spacing level, Gede provenance achieved the highest growth mean (191.2 cm) while Machakos provenance had the lowest mean (117.3 cm). However, at the 5 % level of significance, there were no significant differences between the provenances at the various spacing levels since ($p > 0.05$).

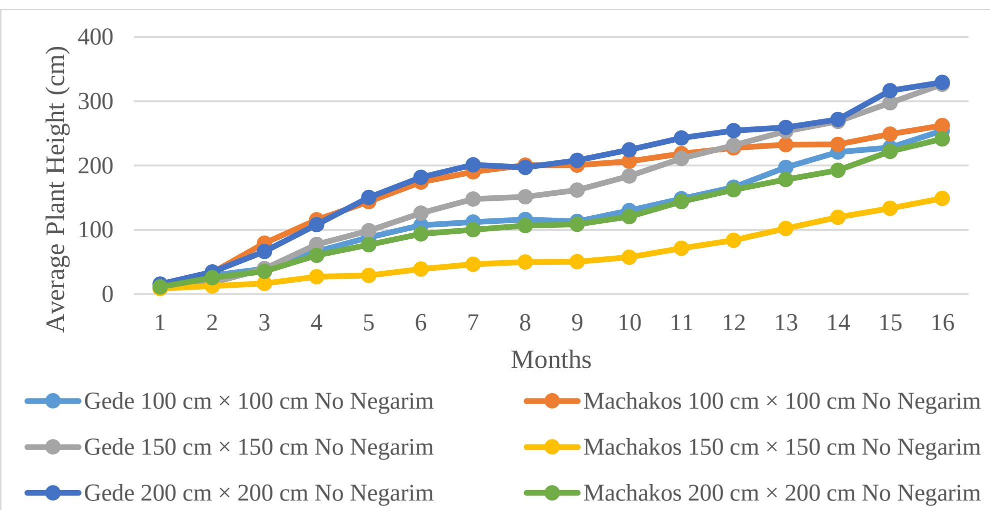


Figure 4.1: Plant Height Growth of *Moringa oleifera* provenances under No Negarim micro catchment

4.1.1.2 Plant Height Growth under Negarim micro catchment

Under Negarim micro catchment, as depicted in Figure 4.2, it was observed that all of the plants' heights increased steadily during the early phases of growth. A fairly similar trend was observed when contrasting the two provenances' average rates of growth in height. At spacing level of 150 cm × 150 cm, Machakos provenance achieved uppermost height of 242.5 cm, whereas Machakos provenance at 100 cm × 100 cm spacing level achieving lowest mean height at 42.9 cm. At 100 cm × 100 cm spacing level, Machakos provenance achieved the lowest mean of 42.9 cm, whereas Gede provenance attaining the highest mean of 82.8 cm. At 150 cm × 150 cm spacing level, Gede provenance attained the lowest mean of 120.4 cm compared to Machakos provenance's mean of 242.5 cm. At 200 cm × 200 cm spacing level Machakos provenance acquired a higher mean of 170.6 cm whereas Gede provenance had a lesser mean of 123.1 cm. However, at the 5 % level of significance, there were no significant differences between the provenances at the various spacing levels since ($p > 0.05$).

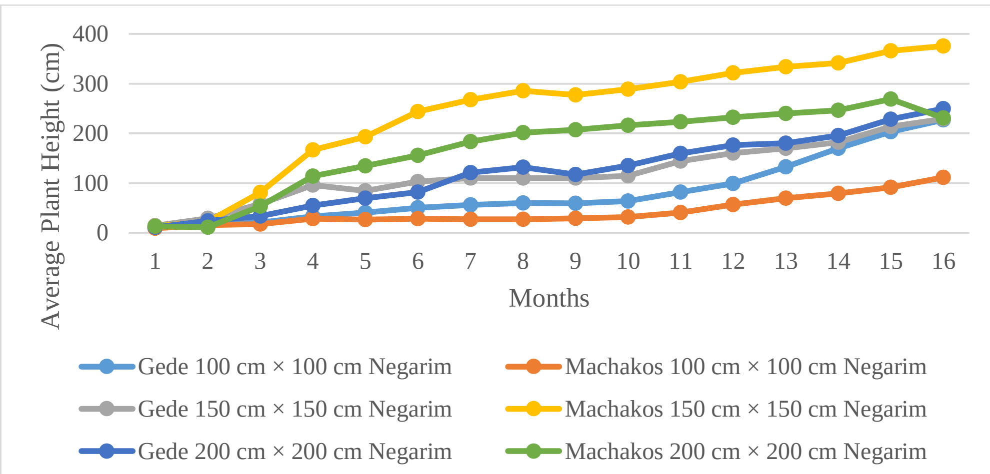


Figure 4.2: Height Growth of *Moringa oleifera* provenances under Negarim micro catchment

In comparison, the Machakos provenance had the largest height increase at the 150 cm × 150 cm spacing level and beneath the Negarim micro catchment, whereas Machakos provenance at the 100 cm × 100 cm spacing level and under Negarim had the lowest growth in height. The Machakos provenance under normal conditions had the highest mean height at 100 cm × 100 cm, while the Machakos provenance under Negarim micro catchment had the lowest. The mean height ranged from 42.9 to 173.6 cm. for the mean height at the 150 cm × 150 cm spacing level, the Machakos provenance under Negarim micro catchment had the greatest growth mean while the Machakos provenance under normal circumstances achieved the lowest mean, with the mean height ranging from 62.1 cm to 242.5 cm. At spacing level of 200 cm × 200 cm, the mean height varied from 117.3 cm to 191.2 cm with Gede provenance obtaining the largest mean and Machakos provenance attaining the least value. However, at 5 % level of significance, there were no significant effects of spacing, provenance, and Negarim micro catchment on plant height. However, as indicated in Table 4.1, there was a significant effect on height, with the provenance and Negarim micro catchment interaction (p = 0.025).

Table 4.1: ANOVA of Plant Height of two *Moringa oleifera* provenances under different spacing and Negarim micro catchment

Source of variation	d.f.	s.s.	m.s.	F	P. value.
Rep stratum	2	93188.	46894.	8.42	2
Provenance	1	2858.	2858.	0.52	0.480
Spacing	2	25252.	12626.	2.28	0.126
Negarim	1	2503.	2503.	0.45	0.508
Provenance.Space	2	4538.	2269.	0.41	0.669
Provenance.Negarim	1	32269.	32269.	5.83	0.025
Spacing.Negarim	2	2436.	1218.	0.22	0.804
Provenance.Spacing.Negarim	2	33881.	16940.	3.06	0.067

4.1.2 Root Collar Diameter

4.1.2.1 Root Collar Diameter under No Negarim micro catchment

Under No Negarim micro catchment, the two provenances' root collar diameter growth rates were quite similar. According to Figure 4.2, Machakos provenance at 150 cm × 150 cm spacing level had the lowest root collar diameter (1.4 cm), whereas Gede provenance at 200 cm × 200 cm spacing level had the greatest root collar diameter (4.3 cm). At spacing level of 100 cm × 100 cm, Machakos provenance had the greatest mean (3.6 cm), while Gede provenance had the lowest mean (2.6 cm). At a spacing level of 150 cm × 150 cm, the mean for the Gede provenance was highest (3.5 cm), while the mean for the Machakos provenance was the lowest (1.4 cm). Under 200 cm × 200 cm spacing level, Gede provenance had the highest growth mean (4.3 cm) while Machakos provenance had the lowest mean (2.7 cm). However, at the 5 % level of significance, there were no significant differences between the provenances at the various spacing levels since ($p > 0.05$)

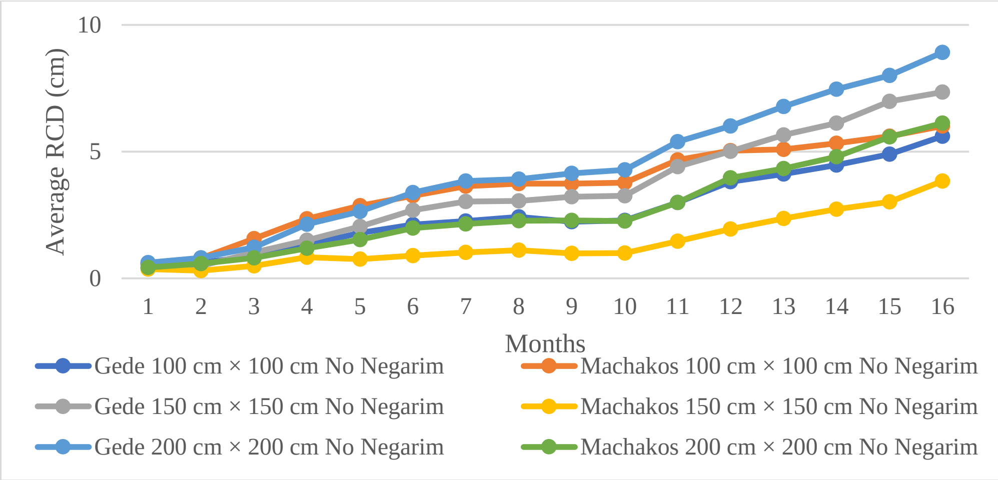


Figure 4.3: Root Collar Diameter growth of *Moringa oleifera* provenances under No Negarim micro catchment

4.1.2.2 Root Collar Diameter under Negarim micro catchment

Similar tendencies in the root collar diameter growth were seen in the two provenances. As indicated in Figure 4.4, Machakos provenance at 100 cm × 100 cm spacing level achieved the lowest mean average growth of 1 cm, whereas Machakos Provenance at 150 cm × 150 cm spacing level had the highest mean of 4.7 cm. Gede provenance had a greater mean of 1.7 cm at 100 cm × 100 cm spacing level, while Machakos provenance had a lesser mean of 1 cm. Under 150 cm × 150 cm spacing level, the mean for the Machakos provenance was greatest at 4.7 cm, whereas the mean for the Gede provenance was the least 2.4 cm. Machakos provenance achieved a greater growth mean of 3.5 cm under a spacing level of 200 cm × 200 cm, but Gede provenance experienced a smaller mean of 2.5 cm. However, at the 5 % level of significance, there were no significant differences between the provenances at the various spacing levels since ($p > 0.05$)

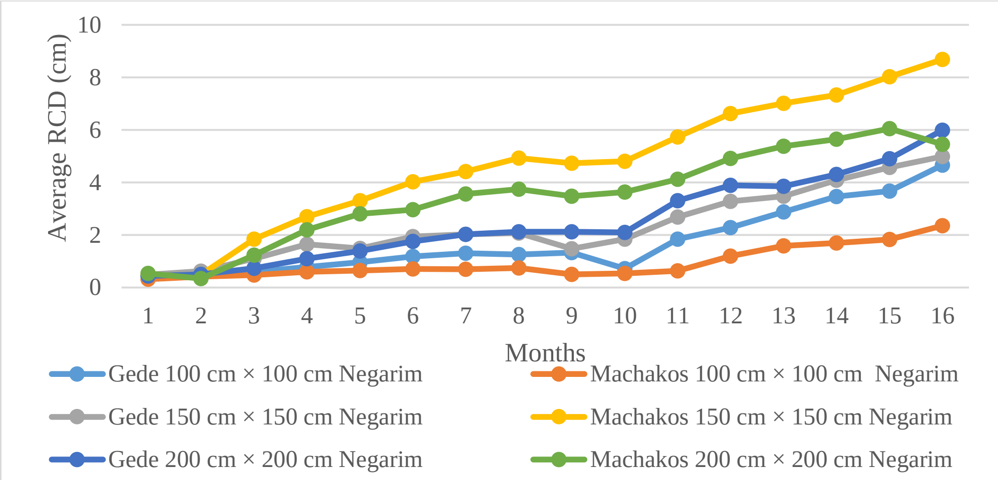


Figure 4.4: Root Collar Diameter Growth of *Moringa oleifera* provenances under Negarim micro catchment

The average root collar diameter for Machakos provenance at 150 cm × 150 cm spacing level and under Negarim micro catchment was highest while Machakos provenance at 100 cm × 100 cm spacing level and under Negarim micro catchment was the least. At spacing level of 100 cm × 100 cm, the mean root collar diameter ranged from 1 – 3.6 cm; Machakos provenance under no Negarim micro catchment achieving the highest mean as compared to Machakos provenance under Negarim micro catchment that achieved the lowest mean. At spacing level of 150 cm × 150 cm, the mean root collar diameter ranged from 1.5 – 4.7 cm; Machakos provenance under Negarim micro catchment achieved the highest mean as compared to Machakos provenance under no Negarim micro catchment that achieved the least root collar diameter mean. At spacing level of 200 cm × 200 cm, the mean root collar diameter expansion ranged from 2.5 – 4.4 cm, with Gede provenance under no Negarim micro catchment achieving the highest expansion mean as compared to Gede provenance under Negarim micro catchment that achieved the lowest mean. At 5 % level of significance, there were no significant effects of spacing, provenance, and Negarim micro catchment on root collar diameter. No significant interaction effects of experimental factors on root collar diameter were observed ($p = 0.064$) as shown in Table 4.2.

Table 4.2: ANOVA of Root Collar Diameter of two *Moringa oleifera* provenances under different spacing and catchment

Source of variation	d.f.	s.s.	m.s.	F	P. value.
Rep stratum	2	64.645	32.322	9.09	
Provenance	1	0.354	0.354	0.10	0.755
Spacing	2	38.757	19.378	5.45	0.012
Negarim	1	0.186	0.186	0.05	0.821
Provenance.Space	2	8.955	4.478	1.26	0.303
Provenance.Negarim	1	13.488	13.488	3.79	0.064
Spacing.Negarim	2	0.064	0.032	0.01	0.991
Provenance.Spacing.Negarim	2	23.552	11.776	3.31	0.050

4.1.3 Branch Development

4.1.3.1 Branch Development under No Negarim micro catchment

Under No Negarim micro catchment conditions, the outcomes of branch development have shown a similar pattern, as seen in Figure 4.5. Machakos provenance at 150 cm × 150 cm spacing level had a mean number of 10 branches, compared to a mean number of 19 branches for Gede provenance at 100 cm × 100 cm spacing level, 150 cm × 150 cm branches for Gede, and 200 cm × 200 cm branches for Gede. Machakos provenance developed a mean number of 19 branches under the spacing level of 100 cm × 100 cm, while Gede provenance had a mean number of 15 branches. Under 150 cm × 150 cm spacing level, Machakos provenance developed a mean number of 10 branches, while Gede provenance developed a mean number of 19 branches. Under a spacing level of 200 cm × 200 cm, Gede provenance had a mean number of 19 branches as opposed to a mean number of 16 branches for Machakos provenance. However, at the 5 % level of significance, there were no differences between the provenances at the various spacing levels as ($p > 0.05$).

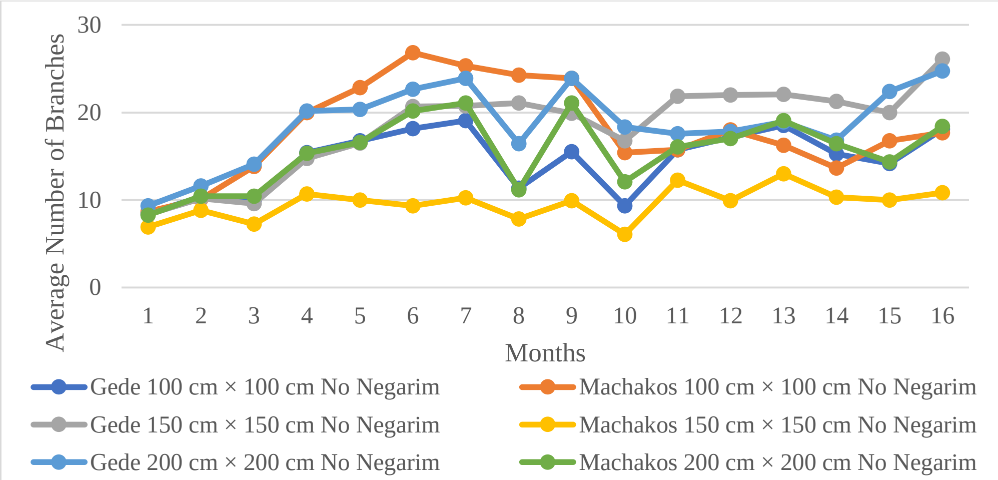


Figure 4.5: Branch Development of *Moringa oleifera* provenances under No Negarim micro catchment

4.1.3.2 Branch Development under Negarim micro catchment

Under Negarim micro catchment conditions, the two provenances' tree primary branches development followed a similar pattern. During the experiment, Machakos provenance at 100 cm × 100 spacing level recorded the least mean number of branches at 8, whereas Machakos provenance at 150 cm × 150 cm spacing level recorded the greatest mean number with 21 branches. Under 100 cm × 100 cm spacing level, Machakos provenance had a lower mean number of 8 branches, whereas Gede provenance had a higher mean number of 13 branches. Under 150 cm × 150 cm spacing level, Gede provenance had a lesser mean number of 14 branches, whereas Machakos provenance achieved a greater mean number of 21 branches. Machakos provenance attained a higher mean number of 16 branches development under the spacing level of 200 cm × 200 cm, while Gede provenance achieved a mean number of 15 branches as depicted in Figure 4.6. However, at the 5 % level of significance, there were no differences between the provenances at the various spacing levels as ($p > 0.05$).

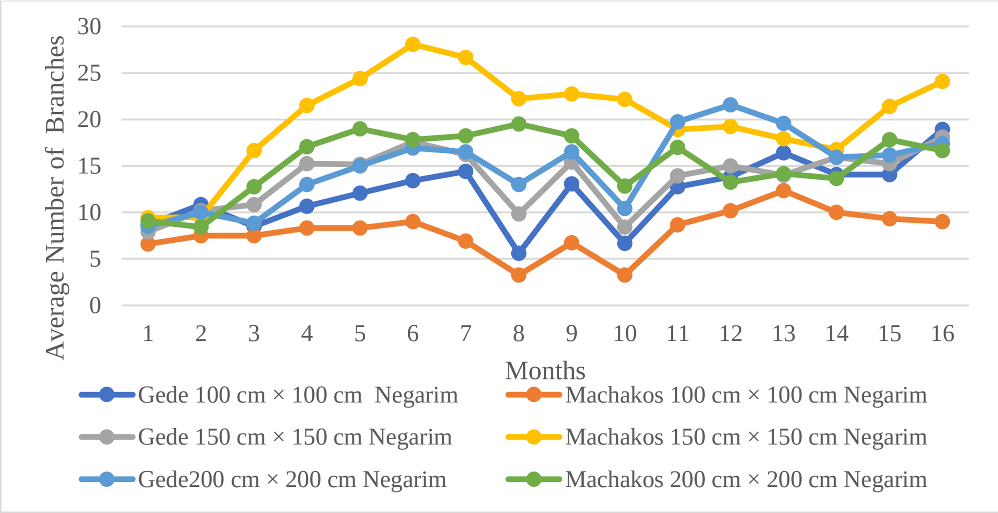


Figure 4.6: Branch Development of *Moringa oleifera* provenances under Neragim micro catchment

In comparison, Machakos provenance at 150 cm × 150 cm spacing level and under Negarim micro catchment had the highest average number of branch development, whereas Machakos provenance at 100 cm × 100 cm spacing level and under Negarim micro catchment had the lowest average number of branch development. The mean number of branches developed at 100 cm × 100 cm spacing levels ranged from 8 to 19, with Machakos provenance under no Negarim micro catchment achieving the greatest mean and Machakos provenance under Negarim micro catchment achieving the lowest number. The mean range of branch development was between 10 to 21 at a spacing level of 150 cm × 150 cm, with Machakos provenance under Negarim micro catchment attaining the greatest mean. At 200 cm × 200 cm spacing level and under no Negarim micro catchment, Gede provenance achieved the greatest growth mean as contrasted to the Gede provenance under Negarim micro catchment, which reached the lowest as the mean number of branch development varied from 15 to 19. At 5 % level of significance, there were no significant effects of spacing, provenance, and Negarim micro catchment on branch development. However, there was a significant effect on provenance and Negarim micro catchment interaction on branch development at 5 % level of significance ($p = < 0.001$) as displayed in Table 4.3.

Table 4.3: ANOVA of Branch Development of two *Moringa oleifera* provenances under different Spacing and Catchment

Source of variation	d.f.	s.s.	m.s.	F	P. value.
Rep stratum	2	368.39	184.19	12.87	
Provenance	1	0.44	0.44	0.03	0.862
Spacing	2	67.56	33.78	2.36	0.118
Negarim	1	5.44	5.44	0.38	0.544
Provenance.Space	2	4.22	2.11	0.15	0.864
Provenance.Negarim	1	277.78	277.78	19.40	<.001
Spacing.Negarim	2	1.56	0.78	0.05	0.947
Provenance.Spacing.Negarim	2	94.89	47.44	3.31	0.050

4.2 Survival Rate of two provenances of *Moringa oleifera* under different Spacing and Negarim micro catchment

4.2.1 Survival Rate under No Negarim micro catchment

Under no Negarim micro catchment conditions, the number of surviving plants in the Machakos provenance at 100 cm × 100 cm spacing level was the greatest at 78 %, while the number of surviving plants in the Machakos Provenance at 150 cm × 150 cm spacing level was the lowest at 57 %. Gede provenance had 70 % of the total live plants under the spacing level of 150 cm × 150 cm, whereas Machakos provenance had 57 %. Gede provenance at a spacing level of 200 cm × 200 cm achieved the lowest survival rate mean at 59 % whereas Machakos provenance had the greatest survival rate mean of 75 %. The plants that recovered after wilting were included in the research. Figure 4.7 depicts the percentage of *Moringa oleifera* in a quite comparable trend for the survival rate of the two provenances. However, at the 5% level of significance, there were no differences between the provenances because ($p > 0.05$).

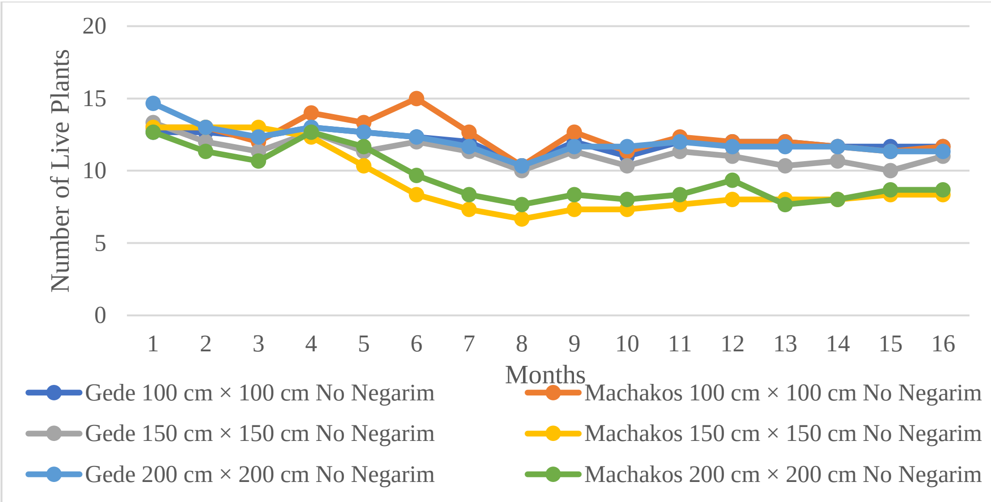


Figure 4.7: Survival rate of *Moringa oleifera* provenances under no Negarim micro catchment

4.2.2 Survival Rate under Negarim micro catchment

Under Negarim micro catchment conditions, the survival rate of the trees in the field for the two provenances followed similar trend. Machakos provenance at 200 cm × 200 cm spacing level experienced an abnormal drop at the 7th month, just like Machakos provenance at 100 cm × 100 cm spacing level at the 8th month. Some of the weathered plants regenerated. Machakos provenance at 200 cm × 200 cm spacing level experienced a slight drop as shown in Figure 4.8 below. Gede provenance at 150 cm × 150 cm had the highest number of surviving plants at 74 % while Machakos provenance at 200 cm × 200 cm had the lowest number of surviving plants at 48 %. Under spacing level of 100 cm × 100 cm, Machakos provenance had a higher survival rate at 62 % while Gede provenance had a lower survival rate at 51 %. Under spacing level of 150 cm × 150 cm, Gede provenance had a higher survival rate at 74 % while Machakos provenance achieved a lower rate of 69 %. Under spacing level of 200 cm × 200 cm, Gede provenance had a higher survival rate of 73 % while Machakos provenance had a lower survival rate of 48 %. However, at the 5% level of significance, there were no differences between the provenances because ($p > 0.05$).

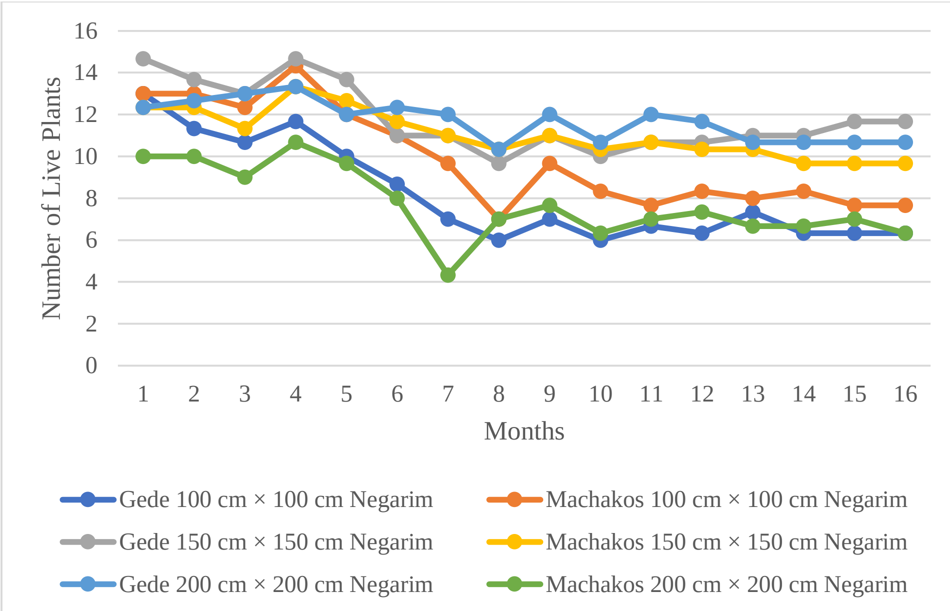


Figure 4.8: Survival Rate of *Moringa oleifera* provenances under Negarim micro catchment

In comparison to Machakos provenance at 200 cm × 200 cm spacing level and under Negarim micro catchment, which had the lowest survival rate at the conclusion of the trial, Gede provenance at 200 cm × 200 cm spacing level and under normal circumstances had a superior survival rate. The mean survival rate varied from 51.04 to 77.47% at spacing levels of 100 cm × 100 cm, with Machakos provenance obtaining the greatest mean and Gede provenance under catchment getting the lowest mean survival rate. The mean survival rate varied from 57.42 to 73.82% at a spacing level of 150 cm × 150 cm, with Gede provenance under catchment attaining the greatest mean and Machakos provenance under normal circumstances obtaining the lowest mean survival rate. At The mean survival rate varied from 48.31 to 75.39% at a spacing level of 200 cm × 200 cm, with Gede provenance under no Negarim micro catchment reaching the greatest mean and Machakos provenance under catchment obtaining the lowest. Spacing, provenance, and the Negarim micro catchment had no statistically significant influence on survival rate at the 5% level of significance. As shown in Table 4.4, there was a significant relationship between spacing and the catchment interaction and the final live plants ($p = 0.033$).

Table 4.4: ANOVA of Survival Rate of two *Moringa oleifera* provenances under different Spacing and Catchment

Source of variation	d.f.	s.s.	m.s.	F	P. value.
Rep stratum	2	2762.6	1381.3	4.23	
Provenance	1	1650.4	1650.4	5.05	0.035
Spacing	2	112.8	56.4	0.17	0.842
Negarim	1	1042.8	1042.8	3.19	0.088
Provenance.Space	2	651.0	325.5	1.00	0.385
Provenance.Negarim	1	87.9	87.9	0.27	0.609
Spacing.Negarim	2	2612.8	1306.4	4.00	0.033
Provenance.Spacing.Negarim	2	182.3	91.1	0.28	0.759

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Effects of Spacing and Negarim micro catchment on growth of provenances of *Moringa oleifera*

5.1.1 Plant Height Growth

5.1.1.1 Plant Height Growth under No Negarim micro catchment

In general, plant height of *Moringa oleifera* trees during the study period were slightly lower under the control treatments. This could be due to the short droughts that occurred during the first three months of the study, water may not have been available to the root zone of trees in the control treatments, which may be the cause of the study's poor growth in plant height. The study demonstrates how traditional tree farming methods are unable to provide the trees with adequate water to support their fast growth and expansion in height. According to Aydrous *et al.* (2015), this may imply the significance of water availability in the root zone and its impact on tree growth. The study's findings concur with those of Xiao *et al.* (2005), who noted the significance of water collecting in guaranteeing a consistent plant development and, consequently, a rise in height.

5.1.1.2 Plant Height Growth under Negarim micro catchment

Increases in height of the provenances varied due to the presence of Negarim micro catchment which gave the catchment experimental units an extra moisture benefit, enabling greater growths in plant height. These findings go against those of Gadzirayi *et al*. (2013), who came to the conclusion that plants grow taller when they are spaced closer to one another owing to competition for light and space, as opposed to when they are spaced farther apart. These findings also go against those of Manh *et al*. (2005), who discovered that varied plant spacing had a significant impact to the height of the plant when equated to its biomass output. In contrast to broader spacing, which saw relatively smaller increases, closer spacing led to a greater rate of height growth.

The Negarim micro catchment provided more moisture to the plants that enabled excellent height increases. Traditionally, it has been believed that trees planted tightly don't produce as many branches that are associated with height increases as those grown with a wider spacing. However, in this study, competition for growing space and light was not observed. This observation supports the claim made by Mall & Tripathi (2017) that there is not much competition for light when plants are between 1.6 and 2.0 meters tall. Additionally, Amaglo *et al*. (2006) came to the conclusion that

Moringa oleifera, as a successful plant crop, exhibited considerable increases in average plant height. They also noted that closely spaced plants experienced a faster growth in height when compared to those plants that had been grown under a wide spacing, which had a slightly lower rate of increase in height. As evaluated by plant height, there was no significant difference between the three plant spacings ($p>0.05$). The reason for this could also be that during the early growth stage, plants are not fully matured, exist as single plants without coppices, and exhibit little competition for growth-promoting resources like light, nutrients, water, and space. As a result, the early growth stage would not be affected by the differential effect of the three-plant spacing under experiment (Gadzirayi *et al.* 2013).

5.1.2 Root Collar Diameter

5.1.2.1 Root Collar Diameter under No Negarim micro catchment

The measurement of root collar diameter growth is an important factor in the overall management of plantation crops because it establishes the proportions of branch dispersion and the following development of fruit and leaf dry matter. It is also noted to be an important conservation and biodiversity tool in view of the fact that larger diameter trees tend to harbor a larger number of species. Root collar diameter increase occurs as a result of secondary growth generated by cell division of the vascular cambium (a lateral meristem) between the xylem and phloem tissues. One of the key elements affecting the morphology and structure of the tree crown is light. This suggests that branches of trees respond to favorable conditions by increasing branch development because higher light conditions in the canopy result in an intensification of photosynthesis and an increase in the production of assimilates (Rufai *et al*. 2016). This concurs with the contention of Valdés-Rodríguez (2018) that the rapid growth of the *Moringa oleifera* stem demonstrates the plant's capacity to absorb essential growth nutrients and water via the roots. In this study, the absence of a significant effect on root collar diameter was because the plants exhibited a similar growth rate as all the plants absorbed water and nutrients at a similar rate, resulting to a similar rate of expansion. Additionally, this finding concurs with the findings of Edward *et al*. (2006) that considerable difference in the provenances were not experienced due to the ability of *Moringa oleifera* in tolerance to the predominant climatic conditions at the study site.

5.1.2.2 Root Collar Diameter under Negarim micro catchment

Catchments have long been utilized to increase the amount of water and moisture that is available in ensuring improved plant development and survival rates. However, the root collar diameter of the *Moringa oleifera* provenances included in this study under different spacings and under Negarim micro catchment exhibited no significant differences. This dispute the findings of Amaglo *et al*. (2006), who found that widely spaced plants experienced a bigger root collar diameter, then those cultivated with a medium spacing, and finally those grown with a smaller spacing. This emphasizes the significance of choosing the appropriate plant density to produce the highest quality and other product yields of *Moringa oleifera* under various climatic conditions. The root collar diameter growth results of this study, which show no statistical differences between the provenances, are in contrast to those of Gadzirayi *et al.* (2013), who found a significant difference among the provenances they included in their study in Zimbabwe. Also, the analysis of this study goes against that of Edward *et al*. (2006), who found a substantial difference among the provenances examined. The findings of this study are consistent with those of Gadzirayi *et al.* (2013), who found no significant ($p > 0.05$) interactions between provenance and spacing on increase in root collar diameter in the two provenances of *Moringa oleifera* included in their study in Malawi.

5.1.3 Branch Development

5.1.3.1 Branch Development under No Negarim micro catchment

Number of branches that developed on the *Moringa oleifera* trees in the control treatment plots at the site during the study period was significantly low. The significantly lower mean of the number of branches that developed under the control treatments may be due to the effect of drought on plant height as well as their effect on encouragement of leaf shedding as a result of water deficit. The effect of water deficit on leaf shedding was very clear under the control treatment as shown in the number of branches during the months of August and October, when it was obviously reduced as compared to other months. Just like Aydrous *et al.* (2015), the study found that during the entire study period, the number of branches was not significantly different among treatments. Also, during the same research, they reported that prolonged dry periods result in loss of leaves. This was also experienced in this research during the months of August and October. This could be attributed to the fact that the period of drought was not long enough for the trees to adapt well to the prevailing dry season and encourage emergence of drought adapted branches and leaves, which may take a considerably longer time.

5.1.3.2 Branch Development under Negarim micro catchment

A provenance with greater number of branches is very critical especially if the plants have been established from seeds is done at early establishment because they ensure sufficient leaf area for light interception, photosynthesis and consequently maximum crop growth and yields (Gadzirayi *et al*. 2013). In this study, the two provenances' capacity to adapt to the unique agronomic and climatic situations where they have been established may have been the reason why there were statistically significant differences between them. Due to the severe drought that was experienced after six months of transplanting, the mean average number of branch developments stalled, slowing the rate of growth. Similar to Usman & Reason (2004), this study defined dry spell as a period of consecutive 5 to10 dry days with a less than 5 mm total amount of rainfall resulting in a soil water deficit causing crop water stress. According to Araya & Stroosnijder (2010), meteorological drought spells are major causes of plant stunted growth in many low rainfall-drought prone environments and in this study, the stunted growth of number of branches developed was experienced during the month of June, at the onset of a relatively dry season.

The findings of this study support ROK's (2010) assertion that June through September are relatively dry months. This is due to the fact that Eastern Kenya has two distinct seasons of precipitation each year: heavy rains from March to May and short rains from October to December (Jaetzold *et al*. 2007). Since the majority of the yearly rainfall falls during the short rains season, which tends to be more dependable for agricultural crop production. Plant growth rates are higher during this season than they are throughout the lengthy rainy season (Getare *et al*. 2021). In this study, the short rains had the highest total season rainfall amounts, which positively influenced soil moisture in comparison to the long rain season; affecting the rate of plant growth and the number of branches that developed on the plants. The amount of moisture around *Moringa oleifera* root zone was enhanced by the presence of Negarim micro catchment units, leading to greater branch development on the plants as they grow.

5.2 Survival Rate of two provenances of *Moringa oleifera* under different Spacing and Negarim micro catchment

5.2.1 Survival Rate under No Negarim micro catchment

The most important rainfall characteristics influencing agricultural production in rainfed systems are the date of onset of effective rainfall, dry spell durations, the time of occurrence of dry spell and number of rainy days (Satpute, 2018). In this study, all these factors contributed to the withering of many plants that were not under Negarim micro catchment. The results of this study revealed that during the first three months of the trial, majority of the *Moringa oleifera* trees in the control treatment withered. This occurred in the generally dry months of January through March (ROK, 2010). Permanent withering affected a few of the plants. This can be ascribed to the trees under the control treatment being exposed to a state of water deficit because of low moisture content in the root zone as a result of insufficient water collection and storage under the modern planting scheme. These results concur with Seidahmed *et al.* (2012) pointed out that the survival of tree species decreased with time as a result of drought due to short rainy season, which affected soil water content. This implies that after transplantation, rain water harvesting can be used to speed up tree establishment, deep root development and to reduce the mortality rate of trees as they grow and develop.

Results of this study are in agreement with that of Subash *et al.* (2012) that rainfall amount and distribution are very critical rainfall characteristics that has an impact on the agricultural productivity in rainfed regions as it has a greater impact on plant survival. According to Rosegrant *et al*. (2002), one of the key problems affecting agricultural systems in ASALs of Eastern Kenya is climate change. This is due to the fact that they exhibit high temperatures as well as irregular, light rains (Jaetzold *et al*. 2007). Low and unpredictable rainfall in these areas causes a lack of soil moisture, which has an impact on plant life. The problem is made worse by an overreliance on rain-fed agriculture, which exposes farmers to the harsh weather that is typical of these regions (Fatondji, 2002). Rosegrant *et al*. (2002) reported that climate change is among the contributing factors to the main challenges facing agricultural systems in ASALs of the Eastern Kenya. Furthermore, according to Yazar & Ali (2016), low precipitation amounts coupled soil water stress and low nutrient availability have been found to limit plant survival in the world's arid and semi-arid environments.

5.2.2 Survival Rate under Negarim micro catchment

The significant differences experienced on Negarim micro catchment and spacing on survival of the two provenances used in this study indicates the better adaptability of the plants under the catchment due to extra moisture collected in the units. This favored the plants, making them to be well adapted to survive. At the study site, it was observed that during the first three months of the experiment, some plants withered and died out due to drought conditions that were experienced and from the third month, some of the plants were able to regenerate. Schulz *et al*. (2013) argued that both environmental conditions and other plant stressors affect differently on the rate of plant survival, and, not all plants can adapt equally when subjected to similar environmental conditions or have a similar level of coping with stressing factors subjected to them.

Al-seekh & Mohammed (2010) mentioned that water harvesting techniques are effective in increasing soil moisture storage, prolonging the growing season and decreasing the amount of supplemental irrigation required for growing fruit trees. The claim made by Dauda & Baiyeri (2009) that micro catchment techniques are suitable for small-scale tree planting in any place with a moisture deficiency lends credence to this. During the study, Negarim micro catchments did not encourage cases of water logging as the units were developed to collect just enough water for plant use. This is in agreement with Abdulkarim *et al.* (2007) and Raja *et al.* (2013) who reported that *Moringa oleifera* can grow well in nearly all soil types that are sandy loam if they are not waterlogged and the plant has abilities of tolerating dry spells in dry seasons of even up to six months (Raja *et al.* 2013). Studies have shown significant differences on how *Moringa oleifera* provenances behave as agricultural crops. Edward *et al.* (2014) reported significant differences in survival of two provenances planted in two different regions in Tanzania. Edward *et al*. (2006) argued that such substantial variances in survival rate could have been attributed to differences in provenances and how they are able to adapt to the pre - existing arid and semi-arid conditions in the areas of the study.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study found that Negarim micro catchment had a significant effect on a number of treatments: there was a significant effect of spacing on height and branch development, unlike root collar diameter of the two *Moringa oleifera* provenances; there was a significant effect of Negarim micro catchment on height and branch development, unlike root collar diameter of the two *Moringa oleifera* provenances; and there was a significant effect of survival rate of the two provenances of *Moringa oleifera* under different spacing and Negarim micro catchment.

6.2 Recommendations

The suitability of Negarim micro catchment in improving growth characteristics and survival of *Moringa oleifera* was evident in this study. Spacing level of 150 cm × 150 cm can be recommended as the most ideal spacing level for use under Negarim micro catchment to be included in agroforestry farming schemes in the study area and in areas with comparable climatical conditions in enhancing the growth and survival traits of *Moringa oleifera*. This is important in ensuring increased production, and utilization by many people in the expanding population. Therefore, this study recommends inclusion of Negarim micro catchment in crop tree cultivation in ASALs during implementation of the Vision 2030 of the tree planting campaign that aims at establishing 1 billion trees that will create jobs to the youth. Also, the study recommends inclusion of Negarim micro catchment in increasing production of *Moringa oleifera,* especially in ASALs; this will enable achievement of the food security clause of the Big Four Agenda. This will lead to increased access to sufficient, safe and nutritious food that meets the dietary needs and food preferences for an active and healthy life to the population living in ASALs. Lastly, more studies on effects of Negarim micro catchment and spacing on biomass production of *Moringa oleifera* provenances in arid and semi-arid area should be undertaken.

REFERENCES

Abdulhamid, B., & Dau, J. H. (2016). Assessment on the effects of potting mixtures on germination and growth of *Moringa oleifera* (LAM) seedlings in Sudan savanna ecology zone of Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, 8(3), 90-96.

Abdulkarim, S. M., Long, K., Lai, O. M., Muhammad, S. K. S., & Ghazali, H. M. (2007). Frying quality and stability of high-oleic Moringa oleifera seed oil in comparison with other vegetable oils. *Food chemistry*, *105*(4), 1382-1389.

Addo, M. M. (2011). *Comparative studies on the effects of moringa oleifera in improving water quality for some communities in Sekyere South District* (Doctoral dissertation).

Adegun M. K., & Ayodele O. J. (2017). Growth and yield of Moringa oleifera as influenced by spacing and organic manures in South-Western Nigeria. *International Journal of Agronomy and Agricultural Research* (IJAAR). Vol. 6, No. 6, p. 30-37.

Adegun M. K., Aye P. A, & Dairo F. A. S. (2013). Effect of plant spacing on fodder yield and re-growth height of Moringa oleifera in south-western Nigeria. *Elixir Applied Botany* 58, 14691-14695.

Adegun, M. K., & Ayodele, O. J. (2015). Growth and yield of *Moringa oleifera* ‘as influenced by spacing and organic manures in South-Western Nigeria. *International Journal of Agronomy and Agricultural Research*, *6*, 30-37.

Al-Ali M. (2012). Soil water conservation and water balance model for micro-catchments water harvesting system. A Thesis Submitted for the Degree of Doctor of Philosophy, Department of Civil and Building Engineering, Loughborough University,

Ali, A., & Yazar, A. (2007). Effect of Micro-catchment water harvesting on soil-water storage and shrub establishment in the arid environment. *International Journal of Agriculture & Biology*, *9*(2), 2007.

Ali, A., Yazar, A., Aal, A. A., Oweis, T., & Hayek, P. (2010). Micro-catchment water harvesting potential of an arid environment. *Agricultural Water Management*, *98*(1), 96-104.

Al-Seekh S. H., & Mohammad, A. G. (2010). The effect of water harvesting techniques on runoff, sedimentation, and soil properties. College of Agriculture, Hebron University, Hebron, West Bank, Palestine. 14th International Soil Conservation Organization Conference. Water

Management and Soil Conservation in SemiArid Environments. Marrakech, Morocco, May 14-19, 2010 (ISCO 2010).

Amaglo, N. K., Timpo, G. M., Ellis, W. O., Bennett, R. N., & Foidl, N. (2006). Effect of spacing and harvest frequency on the growth and leaf yield of moringa (Moringa oleifera Lam.), a leafy vegetable crop. *Ghana Journal of Horticulture*, *6*(1), 33-40.

Anschütz, J., Kome, A., Nederlof, M., Neef, R. D., & Ven, T. (2003). Water harvesting and soil moisture retention. Agrodok-series No. 13; Second Edition. *Agromisa Foundation, Wageningen*, the Netherlands.

Anwar, F., Latif, S., Ashraf, M., & Gilani, A. H. (2007). Moringa oleifera: a food plant with multiple medicinal uses. *Phytotherapy Research: An International Journal Devoted to Pharmacological and Toxicological Evaluation of Natural Product Derivatives*, *21*(1), 17-25.

Araya, A., & Stroosnijder, L. (2010). Effects of tied ridges and mulch on barley (Hordeum vulgare) rainwater use efficiency and production in Northern Ethiopia. *Agricultural Water Management*, *97*(6), 841–847. https://doi.org/10.1016/j.agwat.2010.01.01

Assefa, K. (2021). *Low Flow Analysis for Ungauged catchment in Baro Akobo river basin, Ethiopia* (Doctoral dissertation).

Aydrous A. E., Elamin Mohamed A. M, E. & Abuzied H. M. A. (2015). Effect of Micro-catchment Water Harvesting Techniques on Vegetative Growth of Moringa (*Moringa oleifera*). *Sudan J. Des. Res. 7 (1): 105-123.*

Barrow, E., & Mogaka, H. (2007). Kenya's drylands–wastelands or an undervalued national economic resource'. *IUCN–The World Conservation Union. Nairobi*.

Bayé-Niwah, C., & Mapongmetsem, P. M. (2014). Seed germination and initial growth in Moringa oleifera Lam. 1785 (Moringaceae) in Sudano-sahelian zone. *International Research Journal of Plant Science*, *5*(2), 23-29.

Beckers, B., Berking, J., & Schütt, B. (2013). Ancient water harvesting methods in the drylands of the Mediterranean and Western Asia. eTopoi. Journal for Ancient Studies. ISSN 2192-2608.

Biazin, B., Sterk, G., Temesgen, M., Abdulkedir, A., & Stroosnijder, L. (2012). Rainwater harvesting and management in rainfed agricultural systems in sub-Saharan Africa–a review. *Physics and Chemistry of the Earth, Parts A/B/C*, *47*, 139-151.

Bosch, S. M. & L. Alegre. (2004). Review: Die and let live: leaf senescence contributes to plant survival under drought stress. *Functional Plant Biology*. 31:203-216.

Campbell, B. M., Thornton, P., Zougmoré, R., van Asten, P., & Lipper, L. (2014). Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion in Environmental Sustainability*, *8*, 39–43.

CASL (Community Adaptation and Sustainable Livelihoods). (2006). Arid and semi-arid lands: characteristics and importance.

County Government of Kitui (2014). Integrated Development Plan, *Government Printers*, Nairobi.

Dauda, K. A., & Baiyeri, M. R. (2009). Design and Construction of Negarim Micro Catchment System for Citrus Production. Agricultural Engineering and Water Resources, Institute of Technology, Kwara State Polytechnic, Ilorin, Kwara State, Nigeria.

Demoz, H. A. (2016). A Review on: Effect of Tie Ridging on Crop Productivity in Dry Land Agro-Ecosystems of Ethiopia.

Dobie, P. (2001). Poverty and the Drylands. *Challenge Paper Series, UNDP Drylands Centre*, Nairobi.

Edward, E., Chamshama, S. A. O., & Mugasha, A. G. (2006). Growth performance of lesser-known Leucaena species/provenances at Gairo inland plateau, Morogoro, Tanzania: research note. *Southern African Forestry Journal*, (208), 53-62.

Edward, E., Chamshama, S. A., Ngaga, Y. M., & Mndolwa, M. A. (2014). Survival, growth and biomass production of Moringa oleifera provenances at Gairo inland plateau and Ruvu Coastal Region in Tanzania. *African Journal of Plant Science*, *8*(1), 54-64.

Eze, D. C., Okwor, E. C., Okoye J. O. A., Onah, D. N., & Shoyinka, S. V. O. (2012). Effects of *Moringa oleifera* methanolic leaf extract on the morbidity and mortality of chickens experimentally infected with Newcastle disease virus (Kudu 113) strain. *J. Med. Plant Res.* 6(27): 4443-4449.

Fageria, N. K., Baligar, V. C., & Jones, C. A. (2010). *Growth and mineral nutrition of field crops*. CRC Press.

Fatondji, D. (2002). Organic amendment decomposition, nutrient release and nutrient uptake by millet (Pennisetum glaucum (L.) R. Br.) in a traditional land rehabilitation technique (*Zai*) in the Sahel (Vol. 1). *Cuvillier Verlag*.

Flint, M. L. (2018). *Pests of the garden and small farm: A grower's guide to using less pesticide* (Vol. 3332). *UCANR Publications*.

Foidle, N., Harinder. P. S. Makkar & Becker K. (2001). The potential of *Moringa oleifera* for agricultural and industrial uses. p. 45-76. In L. Fuglie (ed.) The miracle tree: The multipurpose attributes of Moringa. *CTA Publications. Wageningen*, the Netherlands.

Fuglie, L. J. (2001). Natural nutrition for the tropics. *The miracle tree: the multiple attributes of Moringa. CTA/CWS. Dakar, Sénégal*, 103-115.

Gadzirayi, C.T., Kubiku, F.N.M., Mupangwa, J.F., Mujuru, L. & Chikuvire, T. J. (2013). The effect of plant spacing and cutting interval on growth of *Moringa oleifera*. *Journal of Agriculture Sciences and Applications* 2:131-136.

Gandji, K., Tovissodé, F. C., Azihou, A. F., Akpona, J. D. T., Assogbadjo, A. E., & Kakaï, R. L. G. (2020). Morphological diversity of the agroforestry species Moringa oleifera Lam. as related to ecological conditions and farmers' management practices in Benin (West Africa). *South African Journal of Botany*, *129*, 412-422.

Gebreyess, B. F., & Amare, A. (2019). Water harvesting technologies in semi-arid and arid areas. *Journal of Degraded and Mining Lands Management*, *7*(1), 1921.

Geremu, T., Ararso, E., Mamo, D., Ayela, G., Diriba, A., Muleta, B., & Hussen, D. (2016). Effects of negarim and semi-circular structures on growth and yield of banana in moisture deficit area of Daro Labu District, West Hararghe Zone, Ethiopia. *Journal of Horticulture and Forestry*, *8*(4), 32-36.

Getare, E. K., Mucheru-Muna, M., Muriu-Ng'ang'a, F., & Ndung'u, C. K. (2021). Utilisation of *Zai* pits and soil fertility management options for improved crop production in the dry ecosystem of Kitui, Eastern Kenya. *African Journal of Agricultural Research*, *17*(12), 1547–1558. https://doi.org/10.5897/AJAR2021.15760

Hamza T. A. & Azmach N. N. (2017). The miraculous moringa trees: From nutritional and medicinal point of views in tropical regions. *Journal of Medicinal Plants Studies* 5(4):151-16.

Heluf G. & Yohannes U. (2002). Soil and water conservation (tied ridges and planting methods) on cultivated lands. The case of eastern Ethiopian; Soil and Water Management Research Program, *Alemaya University (AU).* 154 p.

Huda N., Haque K. S., Roy B. K. & Sarker N. R. (2017). Seasonal Weather Impacts on Biomass Production of *Moringa oleifera* at Different Fertilizer Doses. *International Journal of Health, Animal Science and Food Safety*, *4*(1).

Ibraimo N. & Munguambe P. (2007). Rainwater Harvesting Technologies for Small Scale Rainfed Agriculture in Arid and Semi-arid Areas. Integrated Water Resource Management. Department of Rural Engineering, Faculty of Agronomy and Forestry Engineering, University Eduardo Mondlane.

Igwilo, I. O., Ogoke, T. J., Ogbu, D. O., Igwilo, S. N., Obi, E., & Abdulsalami, M. S. (2013). Effect of soaked Moringa oleifera seeds on growth rates and the levels of some biochemical parameters in albino rats. *Pakistan journal of biological sciences: PJBS*, *16*(1), 48-50.

IPCC (Intergovernmental Panel on Climate Change). (2007). *Synthesis report. Contribution of Working Groups I, II & III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva Cambridge*. University Press, Cambridge, UK and New York, NY, USA.

IUCN - The Eastern Africa Regional Office. (2006). Country Environmental Profile for Somalia. Report produced for the European Commission Somalia Operations Office, Nairobi, Kenya. Page 60. IUCN Eastern Africa Regional Office, Nairobi.

Jaetzold, R., Schmidt, H., Hornetz, B., & Shisanya, C. (2007). Farm management handbook. *Vol II, Part C, East Kenya. Subpart C*, I.

Kakengi, A., Kaijage, J., Sarwatt, S., Mutayoba, S., Shem, M., & Fujihara, T. (2007). Effect of *Moringa oleifera* leaf meal as a substitute for sunflower seed meal on performance of laying hens in Tanzania. *Livestock Research for Rural Development* 19, 120.

Kathuli, P., & Itabari, J. K. (2015). In Situ Soil Moisture Conservation: Utilization and Management of Rainwater for Crop Production. In W. Leal Filho, A. O. Esilaba, K. P. C. Rao, & G. Sridhar (Eds.), *Adapting African Agriculture to Climate Change: Transforming Rural Livelihoods* (pp. 127–142). *Springer International Publishing*. https://doi.org/10.1007/978-3-319-13000-2_11.

Kenya Forest Research Service (KEFRI) (2014). Tree planting and management techniques under limited water availability. Guideline for Farmers and Extension Agents. *Kenya Forestry Research Institute*, Nairobi, Kenya.

Kenya National Bureau of Statistics (KNBS) (2019). Kenya Population and Housing Census: Volume I. *Kenya National Bureau of Statistics*. ISBN: 978-9966-102-09-6.

Khan, T. I., Dular, A. K., & Solomon, D. M. (2003). Biodiversity conservation in the Thar Desert; with emphasis on endemic and medicinal plants. Environmentalist, 23(2), 137-144.

Khonje, M. G., Nyondo, C., Mangisoni, J. H., Ricker-Gilbert, J., Burke, W. J., Chadza, W., & Muyanga, M. (2022). Does subsidizing legume seeds improve farm productivity and nutrition in Malawi? *Food Policy*, *113*, 102308.

Kiragu J. W., Mathenge P. & Kireger E. (2015). Growth Performance of *Moringa oleifera* Planting Materials Derived from Cuttings and Seeds. *International Journal of Plant Science and Ecology* Vol. 1, No. 4, 2015, pp. 142-148

Koohafkan, P., & Stewart, B. A. (2008). Drylands, people and land use. *Water and Cereals in Drylands; Food and Agriculture Organization of the United Nations (FAO) and Earthscan: Rome, Italy*.

Koul, B., & Chase, N. (2015). *Moringa oleifera* Lam.: Panacea to several maladies. *J. Chem. Pharmaceut. Res*, 7, 687-707.

Laura R, (2004). Water farms: a review of the physical aspects of water harvesting and runoff enhancement in rural landscapes. Technical Report04/6, CSIRO Land and Water, Canberra.

Leone, A., Spada, A., Battezzati, A., Schiraldi, A., Aristil, J. & Bertoli, S. (2015). Cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of *Moringa oleifera* leaves: An Overview. *International Journal of Molecular Sciences* 16(6):12791-12835.

Li, X. Y., Liu, L. Y., Gao, S. Y., Shi, P. J., Zou, X. Y., & Zhang, C. L. (2005). Microcatchment water harvesting for growing *Tamarix ramosissima* in the semiarid loess region of China. *Forest Ecology and Management*, 214(1-3), 111-117.

Liu, Z., Xu, Z., Huang, J., Charles, S. P., & Fu, G. (2010). Impacts of climate change on hydrological processes in the headwater catchment of the Tarim River basin, China. *Hydrological Processes: An International Journal*, *24*(2), 196-208.

Ludwig, F., & Asseng, S. (2006). Climate change impacts on wheat production in a Mediterranean environment in Western Australia. *Agricultural Systems*, *90*(1-3), 159-179.

Luvanda, A. M. (2016). Impact and assessment of charcoal marketing system through community associations in Kitui County, Kenya. *Octa Journal of Environmental Research*, *4*(2).

Mall, T. P., & Tripathi, S. C. (2017). Moringa oleifera: a miracle multipurpose potential plant in health management and climate change mitigation from Bahraich (UP) India–an overview. *Int. J. Curr. Res. Biosci. Plant Biol*, *4*(8), 52-66.

Manh, L. H., Dung, N. N. X., & Ngoi, T. P. (2005). Introduction and evaluation of *Moringa oleifera* for biomass production and as feed for goats in the Mekong Delta. *Livestock Research for Rural Development 17*(9), 4.

Mathenge, P. (2015). Growth performance of Moringa oleifera planting materials derived from cuttings and seeds. *International Journal of Plant Science and Ecology* Vol. 1, No. 4, pp. 142-148.

Matthew, W. F., & Bainbridge, D.A. (2000). Micro catchment water harvesting for desert revegetation. *Soil Ecology and Restoration Group*. Bulletin Number 5.

Mbilinyi, B. P., S. D. Tumbo, H. F. Mahoo, E. M. Senkondo & Hatibu, N. (2005). Indigenous Knowledge as Decision Support Tool in Rainwater Harvesting. *Physics and Chemistry of the Earth.* 30 792–798.

Mendieta-Araica B. (2011). *Moringa oleifera* as an Alternative Fodder for Dairy Cows in Nicaragua. Doctoral Thesis. Swedish University of Agricultural Sciences, Uppsala.

Mishra, S. P., Singh, P., & Singh, S. (2012). Processing of *Moringa oleifera* leaves for human consumption. *Bulletin of Environment, Pharmacology and Life Sciences*, 2(1), 28-31.

Moges Y. (2004). Water Harvesting Techniques: Training and Construction Manual Consultancy Sub-Report No. 2. *Tropical Forestry.*

Molden D., Oweis T., Steduto P., Bindraban P., Munir A. Hanjra & Kijne J. (2010). Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management* 97: 528–535.

Mridha, M. A. U. (2015). Prospects of moringa cultivation in Saudi Arabia. *J. Appl. Environ. Biol. Sci*, *5*(3), 39-46.

Mubvuma M. T., Mapanda, S. & Mashonjowa, E. (2013). Effect of Storage Temperature and Duration on Germination of Moringa (*Moringa oleifera*) Seeds. *Greener Journal of Agricultural Sciences*, 3, 427-432.

Muhl, Q. E (2009). Seed germination, tree growth and flowering responses of *Moringa oleifera* Lam. (Horseradish tree) to temperature. *Faculty of Natural and Agricultural Sciences University of Pretoria. Pretoria*, South Africa.

Muhl, Q. E, Elsa S. du Toit & Petrus J. Robbertse. (2011). Adaptability of *Moringa oleifera* Lam. (Horseradish) Tree Seedlings to Three Temperature Regimes. *American Journal of Plant Sciences*, 2, 776-780.

Muhl, Q. E. (2010). *Seed germination, tree growth and flowering responses of Moringa oleifera lam. (Horseradish tree) to temperature* (Doctoral dissertation, University of Pretoria).

Mundia G. (2003) Clarification and Purification of river water with Moringa oleifera seeds;

Munns, R. and M. Tester. (2008). Mechanisms of salinity tolerance. Annual Review. *Plant Biology* 59:651- 681.

Munyanziza, E., & Sarwatt, S. V. (2003). Evaluation of *Moringa oleifera* for food security and environmental rehabilitation in Tanzanian rural areas. *J. of Tropical Forest Science*, 450-456.

Muriu-Ng'ang'a, F. W. (2017). *Utilisation of selected rainwater harvesting and saving technologies for improved crop production in Tharaka South Sub-County, Kenya* (Doctoral dissertation, Phd Thesis, Kenyatta University, Nairobi, Kenya.

Nabati, J., Nezami, A., Neamatollahi, E., & Akbari, M. (2020). GIS-based agro-ecological zoning for crop suitability using fuzzy inference system in semi-arid regions. *Ecological indicators*, *117*, 106646.

Nelson, D. R., Adger, W. N., & Brown, K. (2007). Adaptation to environmental change: contributions of a resilience framework. *Annu. Rev. Environ. Resour.*, *32*, 395-419.

Obiero, J. P., and Onyando, J. O. (2013). Climate. In Developments in Earth Surface Processes *Elsevier*. (Vol. 16, pp. 39-50).

Olgun, M., A.M. Kumlay, M.C. Adiguzel & A. Caglar. (2008). The effect of waterlogging in wheat (T. aestivum L.). Acta Agriculturae Scandinavica, Section B. *Soil and Plant Science.* 58(3):193-198.

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Simons, A. (2009). Agroforestree Database: a tree reference and selection guide. Version 4. *Agroforestree Database: a tree reference and selection guide. Version 4.*

Oucho, L. A. (2020). The impact of internal migration of youth in developing sustainable counties in Kenya. In *Migration, Remittances, and Sustainable Development in Africa* (pp. 62-81). Routledge.

Padilla, C., Fraga, N. & Suarez, M. (2012). Effect of Soaking Time of Moringa (*Moringa oleifera*) Seeds on the Germination and Growth Indicators of the Plant. *Cuban Journal of Agricultural Science*, 46, 419-421.

Palada, M. C., & Chang, L. C. (2003). Suggested cultural practices for Moringa. *International Cooperators' Guide AVRDC. AVRDC pub*, 03-545.

Parmesan, C. (2006). Ecological and evolutionary responses to recent climate change. *Annu. Rev. Ecol. Evol. Syst.*, *37*, 637-669.

Parrotta J. A., (2009). USDA Forest Service, Research and Development 1601 North Kent Street, Arlington, VA 22209 (USA).

Pérez-Rivera, E. P., Montes-Ávila, J., Castro-Tamayo, C. B., Portillo-Loera, J. J., & Castillo-López, R. I. (2021). Agronomical Aspects of Moringa oleifera (Moringa). In *Biological and Pharmacological Properties of the Genus Moringa* (pp. 39-63). CRC Press.

Pontual, V. E., Belany, E. A. C; Bezerra, S. R., Coelho C. B. B. L., Napoleão, H.T., & Paiva, M. G. P. (2012). Caseinolytic and milk clotting activities from *Moringa oleifera* flowers. *Food Chem*. 135:1848-1854.

Popoola, J. O. & Obembe, O. O. (2013). Local knowledge, use pattern and geographical distribution of *Moringa oleifera* Lam. (Moringaceae) in Nigeria. *Journal of Ethnopharmacology* 150:682-691.

Prăvălie, R. (2016). Drylands extent and environmental issues. A global approach. *Earth-Science Reviews*, *161*, 259-278.

Price, M. L. (2007). The moringa tree. *ECHO technical note, 17391*, 1-19.

Prinz, D., & Singh, A. K. (2000). Water resources in arid regions and their sustainable management. *Annals of Arid Zone*, *39*(3), 251-272.

Qadir, M., Sharma, B. R., Bruggeman, A., Choukr-Allah, R., & Karajeh, F. (2007). Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries. *Agricultural water management*, *87*(1), 2-22.

Radovich, T. (2009). Farm and Forestry Production and Marketing Profile for Moringa (*Moringa oleifera*). *Permanent Agriculture Resources (PAR).*

Raja, R. R., Sreenivasulu, M., Vaishnavi, S., Navyasri, D. M., Samatha, G., & Geethalakshmi, S. (2016). *Moringa oleifera*-An overview. *RA J Appl Res*, *2*(9), 620-4.

Raja, S., Bagle, B. G., & More, T. A. (2013). Drumstick (*Moringa oleifera* Lamk.) improvement for semiarid and arid ecosystem: Analysis of environmental stability for yield. *Plant Breed. Crop Sci*, *5*(8), 164-170.

Rajangam, J., Azahakia Manavalan, R. S., Thangaraj, T., Vijayakumar, A. & Muthukrishan, N. (2001). Status of production and utilisation of Moringa in Southern India. In Proceedings of the International Conference on Development Potential for Moringa Products, Dar es Salaam, Tanzania.

Rana, D. S. (2007). Integrated Water Management, Management of Rain fed Agriculture. *Indian Agricultural Research Institute*, New Delhi – 110 012.

Rani, J., & Paul, B. (2023). Challenges in arid region reclamation with special reference to Indian Thar Desert—its conservation and remediation techniques. *International Journal of Environmental Science and Technology*, 1-22.

Rashid, U., Anwar, F., Moser, B. R., & Knothe, G. (2008). Moringa oleifera oil: A possible source of biodiesel. *Bioresource technology*, *99*(17), 8175-8179.

Ratshilivha, N., Eloff, K., & du Toit, E. S. (2019, November). Vegetative propagation of *Moringa oleifera* trees growing in Pretoria, South Africa, with offsets producing equally consistent bioactivity. In *II International Symposium on Moringa 1306* (pp. 75-82).

Reddy, P. P., & Reddy, P. P. (2016). Micro-catchment rainwater harvesting. *Sustainable Intensification of Crop Production*, 209-222.

Republic of Kenya. (2005). Sessional Paper on Sustainable Development of Arid and Semi-Arid Lands of Kenya (Draft). Page 30. Office of the President, Nairobi.

Reyes-Sánchez N., Spörndly, E., & Ledin, I. (2006). Effect of feeding different levels of foliage of *Moringa oleifera* to creole dairy cows on intake, digestibility, milk production and composition. *Livest. Sci.* 1001: 24-31.

Ridwan, R., & Witjaksono, W. (2020). Induction of autotetraploid Moringa plant (Moringa oleifera) using oryzalin. *Biodiversitas Journal of Biological Diversity*, *21*(9).

Roloff, A., Weisgerber, H., Lang, U., & Stimm, B. (2009). *Moringa oleifera* Lam., 1785. Sea, 10(10).

Rosegrant, M. W., Cai, X., & Cline, S. A. (2002). *World water and food to 2025: Dealing with scarcity*. *Intl Food Policy Res Inst.*

Rufai S., Hanafi M. M., Rafi M. Y., Mohidin H. & Omar S.R.S., **(**2016). Growth and development of moringa (*Moringa oleifera* L.) stem cuttings as affected by diameter magnitude, growth media, and indole-3-butyric acid. *Ann. For. Res*. 59(2).

Saint Sauveur, A. D., & Broin, M. (2010). Growing and processing moringa leaves. *Moringa Association of Ghana (MAG).*

Samy, M. A. (2018). The Potential of Neem, Pongamia Oil and Garlic Extracts Formulation for an Effective Management of Berry Borers in Organic Coffee Plants. *Int J Food Biosci*, *1*, 49-55.

Sánchez, N. R., Spörndly, E., & Ledin, I. (2006). Effect of feeding different levels of foliage of *Moringa oleifera* to creole dairy cows on intake, digestibility, milk production and composition. *Livestock Science*, *101*(1-3), 24-31.

Sarwatt, S., Milang'ha, M., Lekule, F., & Madala, N. (2004). *Moringa oleifera* and cottonseed cake as supplements for smallholders' dairy cows fed Napier grass. *Livestock Research for Rural Development* 16, 6.

Satpute, G. U. (2018). Rainfall Variability and Dry Spell Impact on Rainfed Agriculture in Amravati district of Vidarbha Region in Maharashtra State. *Journal of Agriculture Research and Technology*, *43*(1), 15.

Schulz, S., Brankatschk, R., Dümig, A., Kögel-Knabner, I., Schloter, M., & Zeyer, J. (2013). The role of microorganisms at different stages of ecosystem development for soil formation. *Biogeosciences*, *10*(6), 3983-3996.

SCTD (Schumancher Centre for Technology and Development). (2001). Water harvesting in Sudan. Practical Action, *The Schumancher Centre for Technology and Development*.

Seidahmed H.A, Salih, A.A, & Musnad, H.A. (2012). Rehabilitation of Kerrib Lands in Upper Atbara River using Indigenous Trees and Water Harvesting Techniques, Forestry Research Centre–Soba ARC, *Journal of Science and Technology* Vol. 13 *Agricultural and Veterinary Sciences* (JAVS No.1. 104-109).

Sharma, V., Paliwal, R., Sharma, P., & Sharma, S. (2011). Phytochemical analysis and evaluation of antioxidant activities of hydroethanolic extract of *Moringa oleifera* Lam. Pods. *Journal of Pharmacy Research* 4:554-557.

Siddhuraju P. & Becker K. (2003). Antioxidant properties of various solvent extracts of total phenolic constituents from three different agro-climatic origins of drumstick tree (*Moringa oleifera* Lam.) leaves. *J. Agric. Food Chem*. 51:2144 -2155.

Singh, Y., Sharma, A., Singh, N. K., & Noor, M. M. (2020). Effect of SiC nanoparticles concentration on novel feedstock *Moringa oleifera* chemically treated with neopentylglycol and their trobological behavior. *Fuel*, *280*, 118630.

Studer, R. M., & Liniger, H. (2013). Water Harvesting: Guidelines to Good Practice. Centre for Development and Environment (CDE), Bern; Rainwater Harvesting Implementation Network (RAIN). *Journal of Chemical Information and Modeling*.

Subash, N., Singh, S. S., & Priya, N. (2012). Rainfall variability and its impact on change of cropping systems in Bihar. *Indian Journal of Soil Conservation*, *40*(1), 33–4.

Surbhi S., Upasana Y., & Sheetal S. (2017). Potential of *Moringa oleifera* as a functional food ingredient: A review. International Journal of Food Science and Nutrition. ISSN: 2455-4898. Volume 2; Issue 5.

Tan, M., & Zheng, L. (2019). Increase in economic efficiency of water use caused by crop structure adjustment in arid areas. *Journal of environmental management*, *230*, 386-391.

Texas Water Development Board (TWDB), (2006). Rainwater harvesting potential and guidelines for Texas. *Texas Water Development Board.*

Usman, M. T., & Reason, C. J. C. (2004). Dry spell frequencies and their variability over southern Africa. *Climate Research*, *26*(3), 199–211.

Valdés-Rodríguez, O. A., Giadrossich, F., Pérez-Vázquez, A., & Moreno-Seceña, J. C. (2018). Above-and below-ground biomass and allometry of Moringa oleifera and Ricinus communis grown in a compacted clayey soil. *Flora*, *241*, 35-45.

Vohland K. & Barry B. (2009). A review of *in situ* rain water harvesting practices modifying landscape functions in African drylands. *Agriculture, Ecosystems and Environment* 131 (2009) 119-127.

Walle J. L. & Belayneh A. A. (2014). Yield and Water Use Efficiency of Mulched Drip-Irrigated Onion in Low Land Region of Amhara, North Central Ethiopia. Universal *Journal for Agricultural Resource* 2(6):203-210.

Yazar, A., & Ali, A. (2016). Water Harvesting in Dry Environments. Innovations in Dryland Agriculture. In M. Farooq & K. H. M. Siddique (Eds.), *Innovations in Dryland Agriculture* (pp. 49–98). *Springer International Publishing*.

APPENDIX

Appendix 1: Field Booking Sheet

Date		Cycle	

Plot S/No.	Treatment	Height				Branches				DBH							
1.	Gede 100 cm × 100 cm Negarim																
2.	Machakos 100 cm × 100 cm No Negarim																
3.	Gede 100 cm × 100 cm No Negarim																
4.	Gede 100 cm × 100 cm Negarim																
5.	Machakos 100 cm × 100 cm No Negarim																
6.	Gede 150 cm × 150 cm Negarim																
7.	Machakos 150 cm × 150 cm No Negarim																
8.	Machakos 100 cm × 100 cm Negarim																
9.	Gede 150 cm × 150 cm No Negarim																
10.	Gede 100 cm × 100 cm No Negarim																
11.	Machakos 100 cm × 100 cm Negarim																
12.	Machakos150 cm × 150 cm Negarim																
13.	Gede 150 cm × 150 cm Negarim																
14.	Machakos 150 cm × 150 cm No Negarim																
15.	Gede 100 cm × 100 cm No Negarim																
16.	Machakos 150 cm × 150 cm Negarim																
17.	Gede 150 cm × 150 cm No Negarim																
18.	Gede 100 cm × 100 cm Negarim																
19.	Machakos 100 cm × 100 cm Negarim																
20.	Machakos 100 cm × 100 cm No Negarim																
21.	Gede 100 cm × 100 cm Negarim																
22.	Gede 100 cm × 100 cm No Negarim																
23.	Machakos 100 cm × 100 cm No Negarim																
24.	Machakos 100 cm × 100 cm Negarim																
25.	Machakos 100 cm × 100 cm No Negarim																
26.	Gede 150 cm × 150 cm Negarim																
27.	Machakos 150 cm × 150 cm No Negarim																
28.	Gede 100 cm × 100 cm No Negarim																
29.	Machakos 150 cm × 150 cm Negarim																
30.	Gede 100 cm × 100 cm Negarim																
31.	Gede 100 cm × 100 cm Negarim																
32.	Gede 100 cm × 100 cm No Negarim																
33.	Machakos 100 cm × 100 cm Negarim																
34.	Machakos 100 cm × 100 cm Negarim																
35.	Gede 150 cm × 150 cm No Negarim																
36.	Machakos 100 cm × 100 cm No Negarim																