EFFECTS OF WEEDS ON MORPHO-ECOLOGICAL TRAITS OF SELECTED RANGE GRASSES IN SOUTHERN KENYA

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DECLARATION

This research thesis is my original work and has not been submitted for a degree in any other university for examination.

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ACRONYMS

AEZ	Agro-ecological zones
ASALs	Arid and Semi-Arid Lands
CECI	*Cenchrus ciliaris*
ERSU	*Eragrostis superba*
CHLORIS	*Chloris roxburghiana*
GoK	Government of Kenya
Ha	Hectares
KALRO	Kenya Agriculture and Livestock Research Organization
SPSS	Statistical Package for the Social Sciences
TLU	Total livestock unit

ABSTRACT

The invasion of weeds into rangelands is a precursor for loss of biodiversity, enhanced soil erosion, loss of wildlife habitats, and decrease in carrying capacity for livestock. These weeds are ferocious competitors, often show characteristics of high seedling vigour and short life cycles. The study sought to explore the interactions *Chloris roxburghiana* (CHLORIS), *Cenchrus ciliaris* (CECI), and *Eragrotis superba* (ERASU) under weed infestation. Four treatments were applied during the study: Continuous weeding (W_1), weeding on the 4th week after seeding (W_2), weeding on 6th week (W_3) and the control (no weeding - W_4). The grass species morpho-ecological parameters: plant tillers, grass height, grass density and biomass yield were measured at the grass bloom stage. A comparison of the treatment means and *post hoc* test separation of means statistical analyses were performed. The results illustrated a significant difference ($P \leq 0.05$) in morpho-ecological characteristics of all the weeding regimes. A Pearson correlation analysis showed a positive correlation between biomass (DM) and grass cover, grass density, plant height and tiller density parameters. Continuous weed management and weeding at 4th week of establishment showed the highest biomass performance for *Cenhrus ciliaris, Chloris roxhburgiana* and *Eragrostis superba* species with 1,0651.0 and 8,498.0, 5,185.6 and 4,408.2, 7,364.5 and 5,711.1 Kgs/ha DM respectively. While none-weeding and weeding at 6th week management demonstrated the least performance with 3,604.0 and 6,664.0, 2,441.6 and 3,149.4, 2,257.3 and 4,537.2 Kgs/ha DM respectively. A germination test for seed validity showed an average rate of *Eragrostis superba* (41%), *Cenchrus ciliaris* (35%) and *Chloris roxburghiana* (26%). A farmer survey conducted to determine the cost-effectiveness of applied weed management regimes illustrated that farmers who weeded their pasture farms within the first 3 years since establishment, yielded an extra output of 3kgs seeds, 48kgs crop residual (3.2, 15kg bales) and 138kgs (9.2, 15kg bales) quality grass pasture per acre/season. However, a differential analysis illustrated that the marginal cost was higher than the marginal revenue for pasture weeding with an estimated net marginal loss of between Ksh. 3,726.40 and Ksh. 5,226.40. From the findings, weed management practices has the potential to increase rangeland productivity. Therefore, the national and county governments, through the relevant departments of agriculture and livestock departments should come up with effective range management policy framework that will promote rangeland governance, restoration, pasture production, and livestock production to enhance rangeland livelihoods and ecosystem integrity. Subsidisation of important inputs in pasture production will ease costs of weeding operations, thus,

increasing returns to farmers. Also, it is crucial for the agriculture and livestock departments to structure policies that will easily link livestock producers and pasture farmers to reliable markets for their pasture produce and animal products.

CHAPTER ONE: INTRODUCTION

1.1. Background

Land degradation is a global challenge impacting everybody directly and indirectly through loss of biodiversity, climate change, environmental pollution, food insecurity and rise in food prices (Nkonya*et al.,* 2016). Arid and Semi-Arid Lands (ASALs) are often characterized by extensive rangelands, which are the primary ecosystems that support the livelihoods of pastoralist communities in these regions. The rangelands that largely cover the semi-arid and arid areas (ASALs) mainly consists of natural or semi- natural vegetation of shrubs, grasses, forbs and sages. Rangeland degradation is a key environmental challenge in Sub-Saharan Africa (Mureithi*et al.,* 2015). Bush and weed encroachment into grasslands and pasturelands is the major challenge experienced by the rangelands residing communities. In Sub-Sahara Africa, rangelands make up approximately 48% of total land and they provide a vast range of resources including; habit for wildlife, soil, water and vegetation (Sellers & Devkota, 2022). They also play a major role in accomplishing global sustainable goals such as; climate change adaptation and mitigation, food security and nutrition, creating rural jobs and livelihoods and security, peace and stability (Liniger, & Mekdaschi, 2019).

In Kenya, rangelands occupy about 80% of the total land area. Approximately 40% of the rangelands are degraded, with 2% completely destroyed (Mganga *et al.,* 2015). The southern rangelands of Kenya have been heavily affected by weeds varying from the perennial to annuals mainly the forbs and herbaceous species that are unpalatable to livestock. The weeds are menace affecting the soils, vegetation and socio-economy of the rangelands (Lemus & Weirich, 2010).

This situation is exacerbated by a burgeoning human population exerting unprecedented pressure on scarce rangeland resources, particularly through overgrazing on fragile soils supporting low quality and inadequate pastures (Opiyo *et al.,* 2011).

The primary economic activity carried out by agro/pastoral groups living in rangelands is livestock production, often free-ranging grazing on open grasslands. However, due to mismanaged grazing practices as manifested by disappearance of vital native grass species such *as Cenchrus ciliaris, Enteropogon macrostachyus* and *Eragrostis superba* rangelands degradation present a serious threat to the ecosystem integrity and rangelands livelihoods (Mganga *et al.*, 2015). Additionally, degraded grasslands exacerbate the invasion of unwanted weeds (Ouko *et al.,* 2020). Bush encroachment and extreme weather conditions has pushed the communities residing in rangelands to diversify sources of livelihoods as survival mechanism. (Bailey *et al.*, 2019). Good management of rangelands can help in addressing global challenges such as climate change adaptation and mitigation.

The invasion of weeds into rangelands is a major cause for biodiversity loss, soil erosion increase, habitat loss, and decline in livestock carrying capacity. These weeds often show aspects of high seedling vigour and short life cycles (Frost *et al.,* 2003). Invasive weeds compete with grass pastures for limited water and nutrient resources, they also cause change in the soil microclimate affecting the hydrological cycles and the nutrients cycles that make up the important aspects for pasture growth and nourishment (Yassin, 2019).

Generally, weeds results in reduced quality and quantity of hay and pasture which in return lower the value of livestock production in Rangelands. Additionally, weeds affect the socio economy of communities living in ASALs through reducing the livestock carrying capacity, livestock production resulting to poor human and animal health (Kinnaird & O'brien, 2012). This continues in the face of global challenges more so climate change and weather variability that promote increase in weeds population, species and resistance to control measures (Ziska, 2016). *Ipomea kituiensis* is a good example of a destructive weed in south Eastern Kenya that usually emerge after heavy rainfalls.

Appropriate measures have to be taken towards control of weeds in Rangelands otherwise this may aggravate the already challenging economic situation caused by drought and low rainfall seasons. Timely weed control reduces weed diversity, weed density and weed biomass (Kisambo *et al.*, 2023). Good management of pasturelands can increase animal and plant productivity, improve soil fertility, reduce input cost which in return leads to economic growth (Rinehart 2020). Understanding of information on identification of weeds, weed biology and their environmental impacts, and their value or harm to pasturelands is key to farmers for effective weed management strategy (Lemus & Weirich, 2010). This research aims establish the weed interactions of three range grasses; *Chloris roxburghiana*, *Cenchrus ciliaris*, and *Eragrotis superba*, being championed for adoption by agro pastoralists to improve productivity in southern Kenya rangelands. The selected grass species are suitable livestock forage and have been successfully used in the restoration of degraded semi-arid rangelands in Kenya (Mganga *et al.*, 2015).

1.2. Statement of the problem

Land degradation poses a significant problem in Sub-Saharan African rangelands (Mganga *et al.*, 2015). Loss of biodiversity, in particular plants, has been attributed to land degradation, climate change, and the spread of noxious range weeds (Obiri *et al.,* 2011). Moreover, the impacts of degradation coupled with global climatic change continue to threaten rangeland communities' social and environmental integrity. These communities experience economic loses and exacerbated poverty since they greatly depend on the limited rangeland resources as their source of livelihoods (Mganga *et al.*, 2010).

Additionally, the weed species cause reduced quality of forage and, yield, soil depletion, grazing interference, animal poisoning, and increased costs in land management (DiTomaso, 2000). Semi-arid and Kenya's arid landscapes have been infested with deadly weeds such as *Ipomoea kituiensis* (Mganga *et al.*, 2010). However, this study area has received scant research attention and, at times, neglected despite the looming burden on rangeland ecosystems' socio-economic and environmental aspects. This study analysed the effects of weeds on the performance of three essential rangeland grasses, *Cenchrus ciliaris, Chloris roxburghiana* and *Eragrotis superba* that are in the initial stages of adoption by the agro-pastoral communities as part of the County government's strategy to bulk feed for livestock production during periods of feed scarcity.

1.3. Justification of the study

Droughts are expected to increase in intensity, duration, and frequency with the effects of climate change resulting in increased aridity in rangelands. In the midst of climate change impacts, weeds encroachment into rangelands has become a serious threat to rangeland productivity. Therefore, it is crucial to understand grass-weed interaction effects on the morpho-ecological traits of selected grass species. The southern Kenya rangelands have experienced droughts in the recent past, and weeds invasion has become a serious threat to livestock production and general productivity. The study is a basis for promoting adoption of agronomic practices and the selected range grasses in pasture production and rangelands rehabilitation respectively, both aimed at enhancing rangeland productivity.

The grasses that were used in this study are; *Chloris roxburghiana*, *Cenchrus ciliaris*, and *Eragrotis superba*. They were selected based on their multipurpose uses among pastoral communities e.g., livestock forage, their potential to restore degraded land, and adaptive mechanisms for survival in the African drylands. Furthermore, new knowledge generated on the potential of these perennial grasses will be utilized for forage production and range rehabilitation under grass-weed interactions.

This research recommends strategies for weed management that are cost-effective and that will ultimately contribute to the enhanced restoration of rangelands for improved quality forage production and biodiversity. Similarly, it will go a long way in reducing economic losses incurred along the livestock value chain occasioned by competition from weed species in grasslands. Information from this study will also be helpful for pastoralists, agro pastoralists, pasture farmers, range managers, and government authorities for proper pasture management. More specifically, this study is vital for increased livestock productivity among the agro-pastoralist community of Kiboko of Makueni County of Kenya.

1.4. Objectives

The primary objective of this study was to assess the performance of three rangeland grasses under grass-weed interactions subject to different weed control regimes for improved pasture management in the southern rangelands of Kenya.

The specific objectives were to:

i. Determine biomass production and morpho-ecological traits growth responses under grass-weed interactions.
ii. Evaluate the cost-effectiveness of applied weed management regimes and farmer willingness to practice in the study area.
iii. Establish the socioeconomic determinants of farmer pasture production adoption in South-eastern Kenya rangelands.

1.5. Hypotheses

i. The performance and growth responses of morpho-ecological traits of range grass are similar for all weed control regimes.
ii. The costs and benefits associated with applied pasture weed management are similar across weeding regimes.
iii. All socio-economic factors equally influence farmers' willingness to adopt pasture production in the study area

CHAPTER TWO: LITERATURE REVIEW

2.1. Rangelands of Kenya

According to Ogutu *et al.* (2016), approximately 512,586.8 km^2 is covered by rangelands, accounting for 88% of Kenya's total land area of 582,646 km2. These lands are arid, semi-arid, or hot with erratic rainfall, usually less than 600 mm annually, making them extreme to drought and unsuitable for arable farming. On the other hand, rangelands are home to 32.6% of Kenyans, mostly pastoral communities, and are essential for Kenya's large-scale livestock production and wildlife conservation (Ogutu *et al.*, 2016).

More than 50% of Kenya's livestock population lives in rangelands, where they are primarily raised for their milk and meat. Additionally, more than 70% of the country's protected wildlife reserves and parks are situated in these areas, as well as 65-70% of the terrestrial wildlife populations that exist outside of protected regions. These rangelands cover over 70% of the total land in Kenya (GoK, 2015), and serve as the habitat for both pastoral communities and wildlife, as stated by RCMRD in 2020. In the 2020 report, the Regional Centre for Mapping of Resources for Development (RCMRD) illustrates that the tourism sector and livestock production on Kenya's rangelands together account for over 12% of the agricultural GDP (which is 40% of the national GDP). Families living in the ASALs of Kenya primarily depend on livestock production as the as the primary form of livelihood for food and income (Omollo, 2017). Specifically, many pastoral and agro-pastoral communities depend on livestock keeping to earn income. Therefore, rearing of livestock is one of the major agricultural activities in the country.

Degradation of African rangelands has been promoted by a number of factors such as increased human population, sparse vegetation cover, livestock stamping on fragile soils, and weak soil structure. These factors negatively affect pasture and fodder production in such lands, impacting agro pastoralism. However, despite the degradation, agro pastoralism still remains the most suitable land use in these landscapes. Agro pastoralism is practiced by communities living in semi-arid rangelands in Africa, and it mainly consists keeping of indigenous livestock breeds such as cattle, poultry, goat, and sheep as the primary source of income (Nyangito *et al.,* 2009; Mganga *et al.,* 2015). Thus, good productivity of the grasses and livestock in the rangelands is very crucial.

Evidently, agro pastoralism is the key livelihood strategy in the rangelands with great potential for the production of rangeland products. Particularly, livestock keeping is a significant economic activity in these lands. Livestock production and productivity are dependent on various factors including pasture resources such as range grasses. According to Higashiyama and Hirata (2005), the major factors that affect animal production are categorized into biological, economical, and environmental aspects. Biological factors include health and diseases, breeding and reproduction, and nutrition and feeding. Proper nutrition and feeding are vital for positive yields in livestock production as it promotes good health in the livestock. In rangelands, the grass that grows there offers the primary feed for livestock production and thus, it is important to ensure the animals feed on the best and most nutritious grass.

2.1.1. Rangeland grasses of economic importance

Major rangeland plants such as grasses, shrubs, and forbs are key sources of forage for livestock production with grasses being the most commonly relied upon. Some rangeland grasses have high forage value while others have low and medium. According to Kidake *et al*. (2016), there are various species of rangeland grasses including the native species such as *Eragrostis superba*, *Chloris roxburghiana*, *Enteropogon macrostachyus*, and *Cenchrus ciliaris*. Other grass species in the rangelands also include *Brachiaria sp, Sorghum drummondii*, *Colombus grass, Panicum maximum, Digitaria macroblephara, Themeda triandra,* and *Chloris gayanaextozi* (Kidake*et al.*, 2016).

In Kenya, the rangelands lie in three ecological zones that is ecological zones III, IV, and V, comprising Dry sub humid, Semi-arid and Arid areas respectively. Different grasses grow well in the various zones. According to Infonet-biovision (2022), the major grasses that grow in zone III include *Hyperenia and Cymbopogon, Themeda triandra, Panicum maximum, Setaria sphacelata, Sporobolus pyramidalis*, *Brachiaria brizantha* (Congo signal), *Brachiaria siluta, Chloris gayana* (Rhodes grass) and *Cynodon dactylon* (Star grass). The grass species common in zone IV include *Themeda triandra, Pennisetum mezianum, Pennisetum straminium, Pennisetum massaiense, Eragrostis spp., Hyperenia spp.*, *Setaria spp.*, *Digiteria spp., Bothriochloa insculpta, and Cenchrus ciliaris. Chloris spp. and Cynodon spp.* are also found in this zone, although they are quite rare. In zone V, the most prevalent grasses include *Eragrostis superba, Cenchrus ciliaris*, *Cymbopogon spp., Bothriochloa spp. and Heteropogon contortus* (Infonet-biovision).

Although native grasslands are known to adapt to extreme weather conditions, various factors affect them and thus affecting animal production. According to Wolters (2019), grasslands are endangered by habitat loss which can be brought about by human activities including crop clearing, overgrazing, and unsustainable agricultural activities. Additionally, Opiyo *et al. (*2011) state that the pastoral production resource base has shrunk due to encroachment into grazing areas by cultivation and settlement, as pastoralists are increasingly confined to less productive ASALs. Similarly, the effects of drought, overgrazing, inappropriate cultivation, and termites, have diminished or led to the total loss of some critical forage species, especially grasses. Examples of the critical forage species that have largely diminished include *Eragrostis superba, Chloris roxburghiana, Enteropogon macrostachyus,* and *Cenchrus ciliaris* (Opiyo *et al.,* 2011).

Conservation groups and various organizations around the world have called for the protection of grasslands. There are various methods of protecting grasslands such as prescribed burning, pest management, prescribed grazing, and rangeland reseeding (Schohr, *et al*., 2020). Rangeland reseeding is primarily done to increase the current ground cover and biomass to a level that may not be feasible through grazing management alone. Different studies present reseeding as one of the most successful methods of improving range production. Reseeding helps maintain the desirable grasses that are prone to be lost. According to Opiyo (2007), the success of grass reseeding depends on the site's conditions, rainfall amount, and soil type.

2.1.2. Improving range production through grass reseeding

Grass reseeding is a method of rehabilitating degraded rangelands that involve the introduction of new seeds to replace a depleted seed bank. According to Mganga *et al.* (2015), grass reseeding involves using the seeds of superior plants to reseed the denudated land or establishing completely new pastures with or without irrigating them. A study by Nyariki *et al.* (2004) illustrate that the most successful grasses in reseeding degraded rangelands are the native grasses found on the sites. Mganga *et al.* (2015) identify six types of indigenous perennial grass species that are commonly used in the restoration of degraded semi-arid rangelands in Kenya including *Chloris gayana, Chloris roxburghiana, Cynodon dactylon, Enteropogon macrostachyus, Cenchrus ciliaris, and Eragrostis superba*.

A study by Mganga (2009) ranked the most preferred grass species for reseeding starting with *Eragrostis superba* as the first one followed by *Cenchrus ciliaris with Chloris roxburghiana,* and *Enteropogon macrostachyus* as third and fourth, respectively. Another study by Manyeki *et al.* (2015) involved a cost-benefit analysis of reseeding using the grass species of *Cenchrus ciliaris, Chloris roxbohurghiana, Enteropogon macrostachyus, and Eragrostis superba.* The study found out that reseeding is economically beneficial since the cost incurred in the process is recovered and extra benefits realized.

The current study focused on three grass species, that is, *Chloris roxburghiana, Cenchrus ciliaris*, and *Eragrostis superba* which have been proven to be amongst the best and most preferred species utilized for reseeding and improvement of rangeland production. These grasses quickly establish themselves when exposed to their optimal conditions and adapt well to semi-arid conditions. According to Mganga *et al.* (2019), these grasses are also widely grown for hay production, fodder bulking, production of forage seeds, and silage making. Like other grasses, the three selected types of grass are also affected by weeds to some extent, and thus it is crucial to identify their interactions with weeds and the most effective weeding management practices.

2.1.3. Certification trials for commercial production of range grasses

Once a breeder or scientist has identified a species that needs to be released, the process has several stages. The first stage is Registration with Kenya Plant Health Inspectorate Service (KEPHIS). There are forms to be filled, descriptions of the crop and other information required from the scientist. Secondly there is conduction of Distinctiveness Uniformity and Stability tests (DUS). This is actually an experiment of the grasses registered versus the ones held by KEPHIS. It is a greenhouse or field experiment. This test is done by KEPHIS to authenticate the data provided of the registered species as true and confirm if it is superior to what is in stock already. Mostly it's about yields for livestock related grasses. If it is true that the variety is unique, the next stage is national performance trials (NPT).

Lastly there is Conduction of national performance trials by KEPHIS to verify if it true since it has a database of all released varieties owned by scientists or organizations. The performance experiments are set up to determine if the variety is superior to what exists in terms of yields. These are carried out in different sites of the country depending on ecological conditions described for the grass to grow and at least data for two seasons is required. This data is the normal morphology and yield data. In conclusion when the variety passes this test, the grasses are now formally released and gazetted by the Minister in charge of Ministry of Agriculture.

2.1.4. Morpho-ecological characteristics of studied rangeland grasses

2.1.4.1. *Cenchrus ciliaris*

Cenchrus ciliaris, also known as African foxtail or Buffel grass, is a persistent, tufted perennial grass that occasionally spreads through stolon. It grows in various forms, some of which have become recognized cultivars or strains in cultivation, and is among the most drought-resistant perennial grasses. *Cenchrus ciliaris* is native to tropical and sub-tropical regions of Africa. Several cultivars of this grass species have been developed to improve productivity and resilience under harsh conditions such as drought, frequent fires, and diseases. *Cenchrus ciliaris* is a tufted species that shows considerable variation, with types ranging from ascending to erect and culms that branch out with linear leaf blades that may be flat or have rolled margins (Ogillo et al., 2010).

2.1.4.2. *Chloris roxburghiana*

Chloris roxburghiana, commonly known as Horsetail grass or plume Chloris is a perennial grass species that occurs at 0-1500m above sea level in grasslands and is distributed in the arid and semi-arid counties of Kenya. It is a tufted perennial species that grows up to a height of 120cm. The grass has the widest ecological adaptation in dry areas and is the major component. According to Kenya Agricultural and Livestock Research Organization (KALRO), it is drought tolerant as it only requires a rainfall of 500-625 mm. According to Ogillo (2010), *Chloris roxburghiana* has been successfully used for reseeding eroded rangelands in Kitui, Makueni, and Baringo Counties of Kenya which receive low rainfalls.

The establishment of Horsetail grass requires land to be prepared before the beginning of rains in the ASALs. The preferred preparation methods for this species are by use of ox plough, range pits, no-till, and mechanized land preparation. The seeds are planted through broadcasting and drilling in furrows. The species highly require weed control during the first year which is uprooted by hand or a hoe or by use of selective herbicides. In terms of dry matter, *Chloris roxburghiana* has up to 16% crude protein and 30% crude fibre at an early stage of flowering. Each kilogram of grass yields about 6.6 million naked caryopses that are simple to harvest by hand (Ogillo, 2010).

2.1.4.3. *Eragrostis Superba*

Eragrostis superba, generally known as Maasai love grass or Wilmann love grass, is a densely tufted perennial species which grows to a height of 1m and occurs in areas up to 2100m above sea level. The grass is distributed in the Kenyan ASALs where rainfall ranges between 500 and 875mm. KALRO explains that the preparation of planting land for this grass should be done before the beginning of the rains in the ASALs. The methods of preparing land include the use of range pits, ox ploughs, no-till, and mechanized land preparation. Seed planting is done through drilling furrows and broadcasting at 5kg per hectare with the possibility of adjustments depending on seed germination capacity. Weed control is very important for this grass, especially through the first year, and is done by uprooting by hand or using hoes, or selective herbicides.

According to Mganga (2009), *Eragrostis superba* has been successfully used for reseeding denuded grasslands as it grows in disturbed soils. It grows quickly and is very palatable when young. However, it becomes stemmy and unpalatable as it matures. In its early stages of flowering, the grass has 12% crude protein and 30–35% crude fibre in its dry matter (Mganga, 2009). A study by Wasonga *et al.* (2003) illustrate *that Eragrostis superba* has been identified by the Pokot people in Kenya as one of the most suitable grass species valuable for fattening and enhancing the conditions of their cattle herds.

2.1.5. Performance of rangeland grasses under micro-catchments

Most rangeland grasses require similar micro catchments to retain water due to the low rainfall experienced in the ASALs. Various types of micro catchments are used for rangeland reseeding such as crescent-shaped pits, range pits, burnt plots, and ox furrows. Multiple studies, such as by Ogillo (2010) and Owino *et al*. (2021), have illustrated the benefits of planting grasses under micro catchments in the ASALs. The benefits of micro catchment include the increased capacity of soil water retaining, enhanced seed germination, better seedlings' establishment, and better root growth for the planted grass species (Ogillo, 2010). Additionally, Ogillo (2010) also states that the use of micro catchment is economically viable, especially the ox furrows and range pits.

In the current study, the grasses were planted under ox furrows, one of the most preferred micro catchments in the area under investigation. Ogillo (2010) illustrates that most farmers prefer ox furrows for reseeding as they are less labour intensive and thus can be done in big acreages of land. Additionally, the three types of grass (*Chloris roxburghiana*, *Cenchrus ciliaris*, and *Eragrotis superba*) have been proven to perform well under ox farrow micro catchment (Ogillo, 2010; Ogillo *et al*., 2011). According to Mnene *et al*. (2015), the labour requirements for making ox furrows include bush clearing or removing other invasive species that might be present on the farm. The farm is then ploughed using a tractor or an ox plough, during which the furrows are made. If the grass seed is produced on a small scale, hand tools like jembes may be used to make the furrow micro catchment. The resources required are financial, labour, and machinery such as tractors, jembes, axes, and ox ploughs.

2.2. Weeds in grasslands

Weeds are plants that are out of place, thrive in habitats that have been disturbed by humans, have competitive behaviour, and are capable of mass movement. Plants are defined as weedy based on human values such as disturbed and agricultural habitats, appearance, utility, and biological traits (Dekker, 2011). During reseeding, perennial weeds like docks, buttercups, and creeping thistles may exist as rhizomes or roots in the soil and subsequently sprout up in the new ley. When the seed bank is disrupted during reseeding, they also appear. Rana and Rana (2016) state some common characteristics of weeds as having long seed life in the soil, rapid early growth, and quick emergence. Furthermore, weeds do not require any particular environmental conditions for the germination of their seeds and can survive and thrive in the disrupted environment of a cropped field.

Some cultural and traditional practices also contribute to the spread of weeds and their infestation problems. For instance, the use of organic manure as a method of improving soil fertility is likely to potentially introduce weeds in such lands since the weed seed banks are believed to have increased (Arif *et al.,* 2015). When such weeds grow, they become hazardous as they introduce foreign plants as weeds on cultivated crops and grazing lands. The weeds in pasture then affect their development resulting in low yields and poor seed production. If weeds are not controlled and are allowed to grow, they can lower the total seed quality when the pasture seeds are harvested. Such seeds are likely to be rejected as they do not meet the globally established requirements for seed purity, resulting in financial losses (Kidake *et al.*, 2023). Additionally, when weeds are left in grasslands, they may establish themselves and become difficult to remove.

Weed infestations in grass swards reduce pasture nutritional value while limiting grazing areas and valuable grass growth, especially in newly-sown leys. According to Kidake *et al.* (2023), weeds negatively influence the quality and quantity of pastures which reduces the forage value for animal production. In the semi-arid areas of East Africa, large tracts of land are covered with different types of weeds, competing with the desired grass species for nutrients, space, moisture, and light thus limiting the success of pasture establishment and reseeding. Ekwealor *et al.* (2019) state that some weeds in pasture can be poisonous, calling for the need to be eradicated before mowing. Other weeds might be smelly which is likely to limit the livestock's feed intake, thus compromising productivity. Therefore, management practices such as grazing, topping, drainage, fertility, and mowing are critical when it comes to weed control. All of these factors promote grassland competition and density (Rana & Rana, 2016). Particularly, they help the desired pasture outcompete the weeds and produce as expected.

Though weeds have negative economic and environmental impacts, they may positively contribute to ecosystem function and to people. They increase the species diversity of areas they invade with the implications of adding faunal benefits to the ecosystem (Pratt *et al.*, 2017). This may improve the availability of food resources in an area. Besides food, they also add essential raw materials such as fuelwood, timber, and plant products like resins, edible seeds, and fruits, enhancing the range of habitats and positively influencing the availability of sunlight, water, and nutrients (GISP, 2017). Therefore, in areas where extensive pieces of lands are left for pasture, some weeds might be allowed for these benefits especially the ones that are not smelly and poisonous.

Even though there are several informational resources available, most farmers lack knowledge of good agricultural practices (GAP) for boosting the production of pasture and fodder. Additionally, there is a knowledge gap in the ASALs when it comes to acceptable species, establishment and management of pasture, and even the spread of pasture and fodder technology (Mnene 2006; Kibet et al., 2006). These ventures have been supported by a number of organizations through participatory approaches and have experienced both successes and challenges in the course of their work. (Kidake *et al.,* 2016). Organizations such as KALRO have taken the initiative to train farmers on pasture and forage management within the country. However, a higher percentage of farmers are yet to receive the information.

2.2.1. Common weeds in the study area

In the grasslands of Sub-Saharan Africa, there are diverse types of weeds ranging from introduced or native species that are annual, perennial, or woody. One of the most common alien invasive weed species in grasslands is the *Parthenium hysterophorus* which is common in nearly all grasslands of the world (Mao *et al*., 2021). The weed is an invasive allergenic species that has spread worldwide most probably through the importation of livestock feed, grain seed, and pasture. *Parthenium hysterophorus* seeds germinate optimally under the temperature between 15 and 25°C and can start emerging from a depth of 0–3 cm. According to Huho and Omar (2020), one of the most noxious weed species in East Africa, especially in the ASALs in Kenya, is *Prosopis juliflora*, commonly known as mesquite. The weed is one of the most invasive weed species in arid and semi-arid areas that grows as a thorny shrub of 3-5 meters or a tree of up to 15 meters. According to Julius *et al.* (2020), *Prosopis juliflora* is commonly known as Mathenge in Kenya and was introduced in the 1970s as a way of afforesting the ASALs to curb deforestation.

According to Mganga *et al.* (2021), South Eastern Kenya is prone to the *Ipomoea* weed species that commonly spreads after heavy rains and engulfs sprouting grass seedlings. This weed species is invasive in the Maasai pastoral grazing lands which depresses the productivity of herbaceous biomass. Other common weeds occurring in Kenya include *Bidens pilosa* (Black Jack), *Datura stramonium* (Thorn apple), *Digitaria scalarum* (Couch grass), and *Sonchus oleraceus* (sow thistle) among many others (Koskei, 2016).

Weeds infestation has also highly affected the grass species used for range land restoration and fodder improvement thus influencing the success of the process. For instance, Mganga *et al.* (2021) illustrate that the negative grass-weed interactions and the weeds' competitive nature greatly challenges the establishment and success of reseeding. Therefore, weeds need to be controlled and well-managed to ensure pasture productivity and the success of pasture improvement techniques.

2.2.3. Weed management

Weeds negatively impact the desired plants in various ways such as depressing the yields, contaminating and competing with them for nutrients, and leading to economic losses due to low yields. Weeding helps reduce the yield losses in the desired plants and thus it is highly recommended for increased productivity. The management and control of weeds become more difficult as weeds' coverage increases. Therefore, it is advisable to prevent weeds from increasing early on as they are identified.

One of the most commonly traditionally embraced practices of weed management is grazing rotation in which one spot sprays individual paddocks after grazing it as the herd moves to the next one. In this practice, the weeds are easy to spot as they grow faster encouraging the use of herbicides to destroy them. According to Rana and Rana (2016), it is crucial to possess great grassland management techniques and fully understand the growth habit of specific species. In situations where herbicides are not effective, other practices that can be used to manage weeds include grazing, maintaining soil fertility, mowing, topping, and drainage.

Different weeds require different control methods depending on various aspects such as their growth habits. For example, *Rumex obtusifolius*, commonly known as docks, germinate rapidly after soil disturbance and the plants persist and develop through deep taproots forming dense populations (Merfield, 2019). When mature, docks can produce up to 60,000 seeds per year which can survive for several years in the soil. Therefore, cutting down docks will not control them since new shoots redevelop from the taproot. Additionally, using herbicides to eradicate docks can only be effective at the seedling growth stage but cannot totally kill the established ones. The optimum timing to spray docks should be during the rapid growth period before flowering. *Sonchus oleraceus*, commonly known as Sow thistles, germinate from seeds with the perennial creeping ones being able to spread by underground roots (Merfield, 2019). The roots can remain in a dominating state for a number of years before pushing up shoots into open swards with poor growth. Cutting thistles only weakens them but does not kill the plant. However, spraying thistles with a good herbicide is effective in controlling the plant especially when they are in the vegetative growth stage.

According to Tabe-Ojong *et al.* (2022), the main weed control methods employed in Kenya are manual traditional methods of uprooting and the use of hand tools. Weeding by hand involves the use of cheaply and locally acquired hand tools and equipment such as hoes and scythes. Herbicides for weed control are mostly used in high-value crops such as onions and tomatoes that are market-oriented. However, Herbicides are expensive and require knowledge of use and application. Although the use of manual and herbicides as weed control methods has been highly practiced with other crops, their application on established grasses in ASALs has not been effectively studied. Therefore, one of the goals of this study is to evaluate the cost-effectiveness of applied weed management regimes to inform farmer willingness to practice in the study area.

2.2.4. Grass weed interactions

One of the most studied interactions between grasses and weeds is during the restoration of degraded grasslands. Generally, many invasive plant species including weeds are known to threaten the establishment of the wanted grass species during reseeding as a mode of restoration (Shackelford *et al.*, 2019). This opinion is primarily attributed to the persistent and aggressive nature of the weed species and the ability to adapt to most environments hence colonizing the reseeded areas and out-competing the desired plant species.

Commonly, weeds are known to interact negatively with the reseeded grasses which lead to ecological restoration failures. However, a study by Mganga *et al.* (2021) yielded a positive interaction between weeds and some selected grass species, that is, *Eragrostis superba* and *Enteropogon macrostachyus* in which both the grasses and weeds yielded high biomass when left to grow together. This study by Mganga *et al.* (2021) demonstrated that some grass species can interact with weeds to provide beneficial restoration results, as seen by the high grass biomass output. A study by Cierjacks *et al.* (2016) further explains the positive grass weed interactions by stating that African rangeland soils have limited nutrients characteristics that support such interactions unlike the nutrient-rich soils where just a select few species are able to maximize biomass output in nutrient-dense soils only by out-competing the rest and lead in terms of high biomass production.

Cenchrus ciliaris is also proven to have a competitive and aggressive nature as illustrated in the study by Mganga *et al.* (2021) where it had a higher biomass production compared to the weeds that were left to grow with it. The aggressive nature of *Cenchrus ciliaris* has also been illustrated in other studies such as Marshall *et al.* (2012); Bebawi*et al.* (2013); de Albuquerque *et al.* (2019). Mganga *et al.* (2015) also demonstrated that *Cenchrus ciliaris* has an allopathic nature which can be relied upon as a biological technique of controlling weeds spread in the reseeded grasslands where it is native. However, grass-weed interactions across various combinations of weeding regimes to site specific conditions is yet to be studied.

2.3. Determinants of pasture adoption

In Kenyan grasslands, pasture adoption is practiced in areas where the land is degraded and there is a need to restore it. Various factors influence the decision on pasture adoption including the methods of rehabilitating denuded lands. In Kenyan grasslands, the commonly used methods of restoring degraded lands include deferring grazing, reseeding, and over-sowing. A study by Manyeki *et al.* (2013) sought to find out the social and economic aspects that affect the acceptance of pasture enhancement technologies. The study found out that factors such as the household heads' age and education level, land ownership, and association with farmers' groups influenced the adoption of pasture improvement techniques. Additionally, a study by Njarui *et al.* (2017) also found out the factors that influence the choice of pasture improvement techniques which include the type of livestock management, the agro-ecological zone, and the farm size.

Various studies have been undertaken to find out the factors that determine the adoption of pasture. Some of the most important determinants of the adoption of pasture include the size and tenure of the land and the expertise of the farmers in handling the pasture. A study by Njarui *et al.* (2017), demonstrated that some factors positively influence the adoption of pasture such as land tenure, the level of experience in livestock farming, and access to formal education. Njarui *et al.* (2017) also identified other factors that have a negative influence on pasture adoption including household size, distance to the market, and the size of the farm under consideration. For instance, individuals with large sizes of land are less likely to embrace pasture improvement techniques compared to the ones with small sizes. This is because those with large land sizes can practice rotational grazing where they can have some land time for grass to grow back after grazing as the animals browse on other lands. Presently there is a drive to adopt pasture production as an alternative income activity and thus the need to establish the factors influencing adoption at household level.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Study area

The study was carried out at Kiboko Arid and Range Lands Research Institute land, in the marginal areas of Makueni County, Southern Kenya. Makueni County lies between Latitude 1º 35' south and Longitude 37º 10' and 38º 30' east and covers 7,965.8 km2 with a population of 884,527 in 2009 with annual growth rate of 2.8 % (Amwata, 2013).

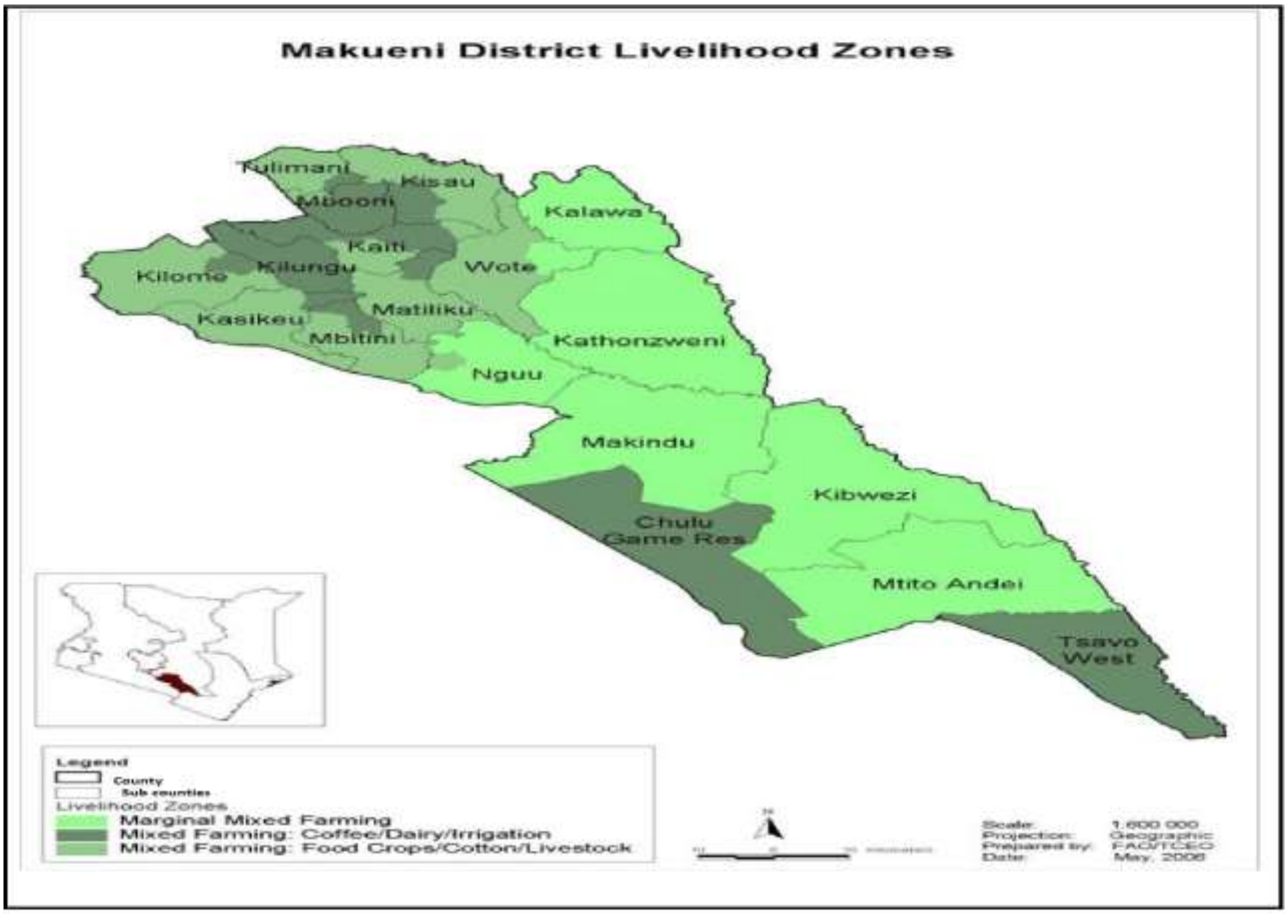

Figure 1: Map showing Makueni County livelihood zones

Source: Ndunda and Muia, (2013).

The County has three main livelihood zones; dairy/coffee/irrigation zone, marginal mixed farming, and food crops/livestock /cotton zone (figure 1). The marginal area is low-lying grassland and has a high potential for ranching. However, crop-livestock farming is the primary land-use system. The marginal regions have limited and seasonal water sources, a large proportion of the community lives below the poverty line, and agricultural production is mainly undertaken under rain-fed conditions.

3.1.1. Climate

In the County, bimodal rainfall season is experienced, with long rains occurring in the months of March to May and short rains from October to December. The region is characterized by low rainfall, less than 500mm annually (Gichuki, 2000), and is prone to drought events. The short rains usually are more consistent and account for 60% of the annual rainfall, with the long rains contributing only about 37% (Gichuki, 2000). This region is hot and dry with a mean annual temperature of 22.6°C, a mean annual maximum of 28.6°C, and an annual minimum of 16.5°C (CYMMIT, 2013). The driest months are June to September (Amwata, 2013). The soil in the area is made up of loose sandy clay to clay (Acri-Rhodic Ferrassols) with a reddish-brown to dark red color. It is well-drained and deep, and is formed from rocks in the basement system, mainly banded gneisses (CYMMIT, 2013).

3.1.2. Vegetation

The County's original fauna and flora has been significantly altered by human interaction, particularly urbanization and settlements. As a result, the area's natural forests are rich in biodiversity and are either gazetted or ungazetted. The gazetted forests include fourteen (14), small forests covering 220 sq. km that spread across the Hinterland and along the coast. This area is dominated by drought-tolerant grass species such as *Themeda triandra*, *Cenchrus ciliaris*, *Enteropogon macrostachyus*, *Eragrostis superba*, and *Chloris roxburghiana.*

3.2. Methodology

A one-acre piece of land was identified at Kenya Agricultural and Livestock Research Organization (KALRO) station at Kiboko in Makueni County. Land preparation was carried out, which involved manual bush clearing, ploughing, and harrowing using a tractor. Weed management practices and grass species planted constituted the treatments. A randomized complete block design with split-plot arrangement was used for this study. The management practice was on the main plot, while the grass species were on the subplot. The field experiment had three replications (figure 2).

Experimental Layout

REPLICA 1			**REPLICA 2**			**REPLICA 3**		
ERASU	CECI	CHLOR IS	CECI	ERASU	CHLOR IS	ERAS U	CHLOR IS	CECI
ERASU	CECI	CHLOR IS	CHLOR IS	CECI	ERASU	ERSU	CECI	CHLOR IS
CECI	CHLOR IS	ERASU	ERASU	CHLOR IS	CECI	ERSU	CHLOR IS	CECI
CHLOR IS	ERASU	CECI	CHLOR IS	CECI	ERASU	CECI	ERASU	CHLOR IS

Figure 2: Experimental design

Key:

CECI - *Cenchrus ciliaris* CHLORIS - *Chloris roxburghiana* ERASU - *Eragrostis superba*	W1	W2	W3	W4

W1-Daily and frequent weeding
W2- Weeding on the 4^{th} week
W3- Weeding on the 6^{th} week,
W4- No weeding

Four treatments were applied: Daily and frequent weeding (W_1), weeding on the 4^{th} weeks (W_2) after sowing, weeding on 6^{th} week after sowing (W_3) and the control-No weeding (W_4). The grass species treatment was *Chloris roxburghiana* (CHLORIS), *Cenchrus ciliaris* (CECI), and *Eragrotiss superba* (ERASU). The grass seeds were sown by hand along furrows at a seeding rate of 5 kg ha^{-1} recommended for indigenous pasture grasses in semi-arid areas of Kenya (Mganga *et al.*, 2021). During the long rain season of March-April-May 2021, the trial was established at 3x3 meter sub plots with a 1m boundary.

3.3. Data collection

The performance of the grasses morpho-ecological parameters was collected at the grass bloom stage at week 8. The parameters were measured from three randomly selected plants within a randomly placed $1m^2$ quadrat in each plot, replicated three times per species. These parameters measured include; Grass cover, % (visually determined cover data), grass density (number of individual grass plants in a 1 m^2 quadrat), grass height (height from the grass crown to the tip of the grass spike in cm), tiller density (number of tillers in a plant), grass biomass, weed cover (%) and weed density (number of individual weed plants in a 1 m^2 quadrat). The above-ground biomass was clipped at the stable height of 5cm. The harvested herbage was placed in labeled brown bags then oven-dried for 48 hours at 60^0C. An electronic weighing scale was used to determine the herbage dry matter (DM). The weights were then extrapolated to production in kilograms per hectare. The seed were harvested at their maturity, 25 days after the grass has bloomed. The seeds were processed, packed and stored in labeled brown bags for 2 months. A germination test for seed viability was thereafter conducted using petri dishes on the lab. The different grass species seeds were clean rubbed using the appropriate sand paper grades (Grade 0 for *Chloris roxburghiana*, grade 1 for *Cenchrus ciliaris*, and grade 2 for *Eragrostis superba*). The clean seeds were arranged on petri dishes lined with filter moist papers. The filter papers were moisturized regularly, while observations and recording done on daily basis for 21 days. The number of seeds germinated were counted against the total number of seeds lodged and calculated in %age.

To determine the cost-effectiveness of applied weed management regimes based on willingness to practice by farmers, a survey was conducted in the study area. The study relied on government and non-government, pasture and fodder training organizations to collect farmer records within Makindu Sub County as the study sampling frame. Data including name of farmer, residence, contacts and adoption status were compiled in a MS Office Excel. A total of 200 farmer records were collected. A multi-stage random sampling design was carried out during data collection. In the first stage, the study area was divided into administrative units/clusters. Where, the clusters were randomly selected. In the second stage, households were sampled within the selected clusters.

The study targeted a total of 5 clusters and 100 farmers within Makindu Sub County. A sample size of 50% is acceptable (Mugenda & Mugenda, 2003).

3.4. Data analysis

Two-Way Anova statistical analysis was done on the morpho-ecological data, to determine Least Square Difference (LSD) between treatments at $P \leq 0.05$. Post hoc test was used to separate the means between the weeding regimes. A Pearson correlation analysis was done to examine the relationship between the measured plant traits. SPSS software version 22 was used to perform the statistical analyses. In the survey study, a differential analysis also known as the alternative cost analysis method was used to estimate the net gain or loss that the farmers earned or incurred by choosing to weed their pasture farms and not doing so. The study used the competitively prevailing market costs and prices to estimate the costs and benefits of weeding for an acre of land for all the farmer technologies adopted. The costs included cost of buying herbicide and labor or manual labor for weeding, while the benefits were the net gains acquired by the farmers from weeding that the other farmers forgone for not weeding. The value of the net gains or losses were assumed to be derived from weeding agronomic practice. An independent t-tests inferential statistics was used to compare the sample means between the weeded and non-weeded pasture treatments using SPSS software version 22. The test analyzed the different factors on how they influenced the farmer decision to adopt pasture production technologies. The model was selected for this study due to the dichotomous nature of the depended variable where the farmers either decided to adopt pasture production or not.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Growth response of range grass morpho-ecological traits under grass-weed interaction

4.1.1. Grass morpho-ecological characteristics

The plant biomass, cover, grass density, plant height and plant tiller density results are shown in table 1 to 5. The results revealed that the treatments significantly ($P \leq 0.05$) influenced the grass morpho-ecological traits. That is, Least Significant Difference (LSD) between treatments and - the Post hoc test on means separation indicated that there was a significant difference between all the treatments. Equally, an Anova sum of squares test showed that for all the treatments, the difference was majorly influenced by the different weeding regimes administered.

Table 1: Biomass (Kgs/ha DM)

Period	Ceci	Chloris	Erasu
6 weeks	6,664.0±14.5^{a}	3,149.4±165^{b}	4,537.2±91^{b}
4 weeks	8,498.0±205^{a}	4,408.2±174^{b}	5,711.1±170^{b}
Continuous	10,651.0±430^{b}	5,185.8±145^{a}	7,364.5±85.5^{b}
None weeded	3,604.0±159^{ab}	2,441.6±185^{b}	2,257.3±21^{ab}

The column means with different superscript are significantly different at $P \leq 0.05$ significance level.

Table 2: Grass cover (%)

Period	Ceci	Chloris	Erasu
6 weeks	80.0±0.0^{a}	56.7±6.7^{a}	70.0±2.9^{a}
4 weeks	88.3±1.7^{b}	56.7±1.7^{a}	83.3±1.7^{b}
Continuous	93.3±1.7^{b}	63.3±1.7^{a}	86.7±1.7^{b}
None weeded	73.3±1.7^{a}	43.3±1.7^{b}	68.3±1.7^{a}

The column means with different superscript are significantly different at P≤0.05 significance level.

Table 3: Grass density (per m^2)

Period	Ceci	Chloris	Erasu
6 weeks	16.7 ± 1.5^a	7.3 ± 0.9^a	12.7 ± 0.9^a
4 weeks	20.7 ± 0.9^b	9.7 ± 0.9^a	17.0 ± 1.0^b
Continuous	29.7 ± 1.2^{ab}	13.3 ± 0.3^b	21.7 ± 1.3^{ab}
None weeded	17.3 ± 0.9^a	5.7 ± 0.3^a	13.0 ± 1.2^a

The column means with different superscript are significantly different at P≤0.05 significance level.

Table 4: Plant height (cm)

Period	Ceci	Chloris	Erasu
6 weeks	83.7 ± 2.4^a	61.4 ± 3.2^a	88.9 ± 2.7^a
4 weeks	88.3 ± 1.6^a	68.4 ± 1.0^a	94.8 ± 0.9^a
Continuous	109.1 ± 3.3^b	84.2 ± 1.8^b	119.1 ± 7.4^b
None weeded	75.5 ± 0.7^a	62.8 ± 0.3^a	83.4 ± 0.3^a

The column means with different superscript are significantly different at P≤0.05 significance level.

Table 5: Tiller density

Period	Ceci	Chloris	Erasu
6 weeks	35.7 ± 5.0^a	12.0 ± 2.1^a	24.7 ± 3.0^a
4 weeks	42.3 ± 2.6^a	15.7 ± 1.8^b	29.0 ± 1.5^a
Continuous	59.7 ± 1.5^b	19.0 ± 1.2^b	41.0 ± 4.7^b
None weeded	20.3 ± 0.3^{ab}	7.3 ± 0.3^{ab}	18.3 ± 0.3^a

The column means with different superscript are significantly different at P≤0.05 significance level.

Continuous weed management showed the highest grass cover, grass density (number of individual plants per m^2), plant height and tiller density, followed by weeding at 4th week of establishment (figure 3). None-weeding management demonstrated the least performances in all the parameters measured. Biomass performances was highest for continuous and weeding at 4th, 6th week and none weeded in that order for all the treatments as shown in figure 3.

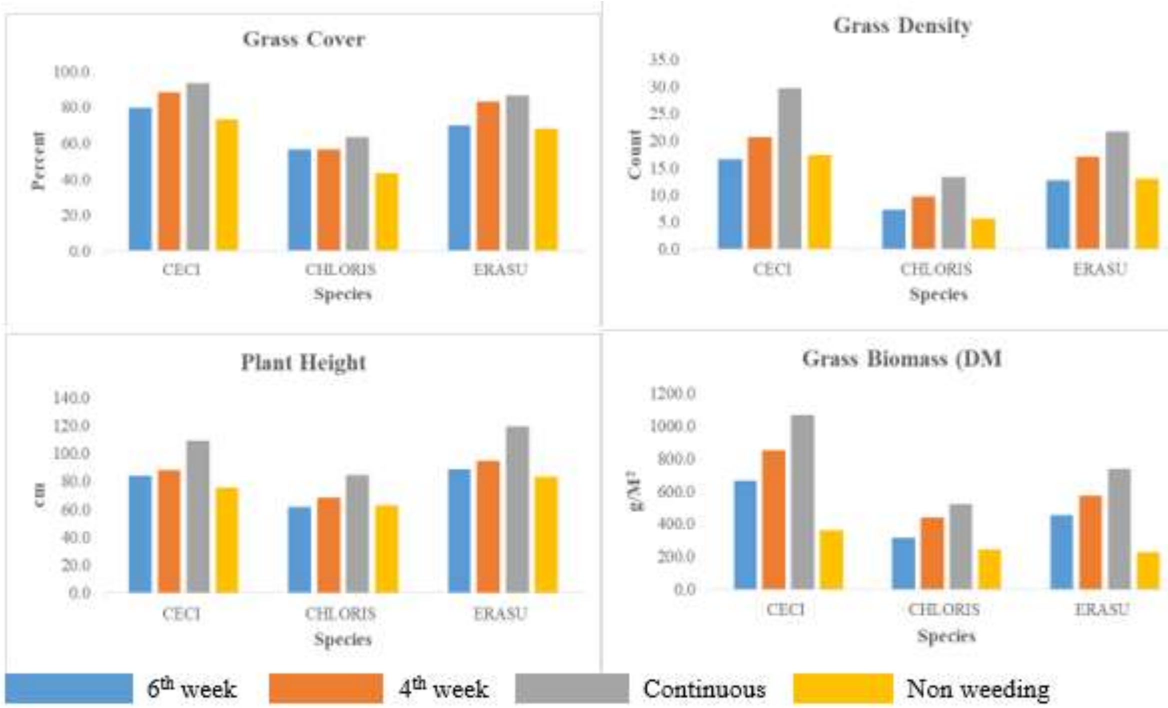

Figure 3: Grass morpho-ecological characteristics

As shown in table 1, grass morpho-ecological characteristics; grass cover (%), grass density, plant height (cm), tiller density and biomass (g/m^2) tend to reduce with prolonged none-weeding period. Plant density and plant cover indices have been used in earlier studies as a measure of successful ecological rehabilitation (Scotton, 2019). From the study results, *Cenchrus ciliaris* displayed more significantly a higher plant densities and cover throughout the weeding regimes as compared to *Chloris roxburghiana* and *Eragrostis* superba (Table 6).

The study results compliment the work of Koech *et al*., (2016), which illustrated that *Cenchrus ciliaris* had the highest plant density and plant cover as compared to *Eragrostis superba* and

Chloris roxburghiana. This can also be associated to *Cenchrus ciliaris* having strong spread root system that enables it to tap nutrients and water from deep soils and outcompete weeds (Heuzé *et al.,* 2016). However, this is in contrary with Mganga *et al.*, (2021) study that found out that *Enteropogon machrostachyus* had highest plant densities and covers relating it to its larger seeds that influenced faster germination and establishment compared to C*hloris roxburghiana* and *Cenchus ciliaris and Eragrostis superba* which had smaller size seed. Also, according to Sanderson *et al.,* (2002), the size of seeds influenced germination rates and emergence rates.

Chloris roxburghiana having the lowest grass density and grass cover as observed in the study results. *Chloris roxburghiana* has a longer seed dormancy, hence few of its seeds germinate leading to low morpho-ecological traits, particularly grass density and cover. According to Baskin and Baskin (2021), 80% of ASALs angiosperms produce seeds that are in a dormant state. Seed dormancy inhibits germination therefore preventing total failure during unfavorable periods for germination.

Eragrostis superba had the highest plant height compared to other grass species. According to Mganga *et al.,* (2021), Plant height gives grass species a competitive advantage for light with other plants (Moles *et al*., 2009). However, this did not confer this grass species a superior advantage across treatments as *Cenchus ciliaris* emerged a better competitor with higher morpho-ecological traits. This suggests that *Cenchus ciliaris* should be the grass of choice for range restoration programs in this study area. Grasses with high tiller densities have the capacity for restoration and improved resilience after defoliation of the above ground biomass and sustenance of food reserves compared to plants with low tiller density (Mganga *et al.,* 2021).

4.1.2. Weed measurements characteristics under different grass weeding regimes

Continuous weed management and weeding at 4th week of establishment, respectively showed the lowest weed cover and weed density. Weeds density and cover increased with prolonged none-weeding treatment. There was a significant difference ($P \leq 0.05$) in weeding characteristics in all the weeding regimes administered from the results (Table 7 and 8). The mean differences were significant at the 0.05 level.

Table 6: Weed cover (%) in grass species under different weeding regimes (per m2)

Period	Ceci	Chloris	Erasu
6 weeks	20.0 ± 0.0^{a}	35.0 ± 5.0^{a}	30.0 ± 2.9^{a}
4 weeks	10.0 ± 0.0^{b}	18.3 ± 1.7^{b}	15.0 ± 0.0^{b}
Continuous	00.0 ± 0.0^{ab}	00.0 ± 0.0^{ab}	00.0 ± 0.0^{ab}
None weeded	26.7 ± 1.7^{bc}	56.7 ± 1.7^{bc}	31.7 ± 1.7^{a}

The column means with different superscript are significantly different at $P \leq 0.05$ significance level.

Table 7: Weed density under different weeding regimes (per m2)

Period	Ceci	Chloris	Erasu
6 weeks	6.3 ± 0.3^{a}	3.3 ± 0.3^{a}	5.3 ± 0.9^{a}
4 weeks	6.0 ± 0.6^{a}	3.3 ± 0.3^{a}	6.3 ± 0.9^{a}
Continuous	0 ± 0.0^{b}	0.0 ± 0.0^{b}	0.0 ± 0.0^{b}
None weeded	9.7 ± 1.7^{ab}	8.3 ± 0.3^{ab}	8.0 ± 1.5^{ab}

The column means with different superscript are significantly different at $P \leq 0.05$ significance level.

The grass species selected for this research have different and unique morpho-ecological characteristics that enable them to thrive in dryland conditions and interact differently with weeds. Weeds density and cover increased with prolonged none-weeded period. Study results displayed that, although *Cenchrus ciliaris* had the highest weed density, it had the lowest weed cover and corresponding highest grass cover and grass biomass. *Cenchrus ciliaris* species was found to have a competitive and aggressive nature to compete weeds thus reducing the weeding liability. This can be related to toxic allelopathic trait of *Cenchrus ciliaris* toward other plants (Friedel *et al.*, 2006). Additionally, according to Heuzé *et al.,* (2016), *Cenchrus ciliaris* has deep, tough roots that can go as deep as 2m and its culms are erect reaching up to 2m high. This gives the grass a competitive advantage over weeds and the rest of the other grass species. This is also the reason as to why *Cenchrus ciliaris* is recommended for use as a weeds biological control method in reseeded and rehabilitated rangelands. This result is in line with earlier findings by Marshall *et al.*, (2012), that areas dominated with *Cenchus ciliaris* had lower weed cover compared to areas with other grasses.

On average, the most weeds on all weeding regimes were herb, legume and woody weeds respectively (Table 9-11).

Table 8: Legume weeds composition (%) under different weeding regimes (per m2)

Period	**Ceci**	**Chloris**	**Erasu**
6 weeks	32.7	37.4	31.9
4 weeks	36.7	35.8	34.3
Continuous	00.0	0.0	00.0
None weeded	34.4	30.3	32.8

Table 9: Wood weeds composition (%) under different weeding regimes (per m2)

Period	**Ceci**	**Chloris**	**Erasu**
6 weeks	13.2	18.7	19.8
4 weeks	13.8	12.3	23.0
Continuous	00.0	00.0	00.0
None weeded	19.1	17.6	21.3

Table 10: Herbaceous weeds composition (%) under different weeding regimes (per m2)

Period	Ceci	Chloris	Erasu
6 weeks	54.1	43.9	48.3
4 weeks	49.4	51.9	42.7
Continuous	00.0	00.0	00.0
None weeded	46.4	52.1	45.9

4.1.3. Pearson correlation

The Pearson correlation showed a positive correlation between grass cover, grass density, plant height, tiller density and grass biomass (DM) parameters. However, there was a negative inter-correlation between weed cover and weed density with grass cover, density, plant height, tiller density and biomass.

Table 11: Grass-weed Pearson correlation

	1	2	3	4	5	6	7
1. Grass Cover	-						
2. Weed Cover	-.724	-					
3. Grass Density	.876	-.737	-				
4. Weed Density	-.237	.664	-.310	-			
5. Plant Height	.781	-.723	.796	-.464	-		
6. Tiller Density	.857	-.696	.921	-.400	.813	-	
7. Grass biomass DM	.734	-.694	.805	-.472	.650	.838	-

Key: Numbers in the first row represent the grass as shown in the left side of table

These results compared well with research findings of Marshall *et al.,* (2012); Bebawi *et al.,* (2013); de Albuquerque *et al.,* (2019) who found a negative interaction between weeds and range grasses. However, the results contrasted the findings of Mganga *et al.,* (2021), who observed that weeds interacted positively with *Eragrostis superba* and *Enteropogon macrostachyus* grass species.

4.1.4. Grass seed viability

The grasses seed viability is presented in table 13 below. *Eragrostis superba* grass species had the highest viability rate, followed by *Cenchrus ciliaris* and *Chloris roxburghiana* respectively.

Table 12: Seed germination (%) for different grass species

Species	Weeded grass % mean	None weeded grass % mean
Cenchrus ciliaris	37	33
Chloris roxburghiana	27	25
Eragrostis superba	43	39

The seed viability results showed no significance difference between the weeded and none-weeded grasses. The seed viability differences observed among the grass species can be linked to differences in behavioral and morpho-ecological traits. Such traits include; seed dormancy caused by seed coat hardness, unfavorable climatic conditions such as extreme temperatures and low moisture (Mganga, 2010). The high viability of *Eragrostis superba* also can be linked to having lager seeds sizes which gave it competitive advantage for faster uptake of moisture and germination compared to the other smaller grass seeds.

4.2. Cost-effectiveness of farmer weed management regimes

4.2.1. Demographic characteristics of farmers

Majority of the respondents (82%) were aged between 36-60 years, representing the middle aged, others were aged 18-35 representing the youth and above 60 group representing the senior citizens. Among the respondents, 40.9% were secondary school graduates, 31.8% were primary school certificate holders while 13.6% had achieved tertiary level of education (Table 14).

Table 13: Pasture farmer demographic characteristics

Characteristic	Description	% n=80
Gender of the farmer	1 Male	34.09
	2 Female	65.91
Age category of the farmer	1 18-35	09.09
	2 36-60	81.82
	3 Above 60	09.09
Highest level of education	1 Pre-primary	13.64
	2 Primary	31.82
	3 Secondary	40.91
	4 Tertiary	13.64
Main source of livelihood	1 Crop	36.36
	2 Pasture	34.09
	3 Livestock	29.55
Access to technical training	1 Yes	56.83
	2 No	43.18
Access to extension support	1 Yes	25.00
	2 No	75.00

Among the farmers interviewed, most practiced crop (36.3%), pasture (34.0%) and livestock production (29.5%) as their main type of farming and source of livelihood. Amongst them, 56.8 had access to pasture technical trainings and 25% had access to local extension support.

4.2.2. Pasture production

In the study area, the mean size of land under pasture establishment was 3.9 acres. While the farmers had a mean pasture production of 3.3 years.

Table 14: Pasture production attributives at farm level

Item	**Mean (n=80)**
Land Resource (Acres)	3.9 ± 1.2
Pasture experience (Years)	3.3 ± 0.7

Majority of the farmers (40.9%) had adopted pasture production for both seed and hay. These farmers were closely followed by those practicing only pasture seed production (36.3%) and hay production (22.7%) as shown in figure 4.

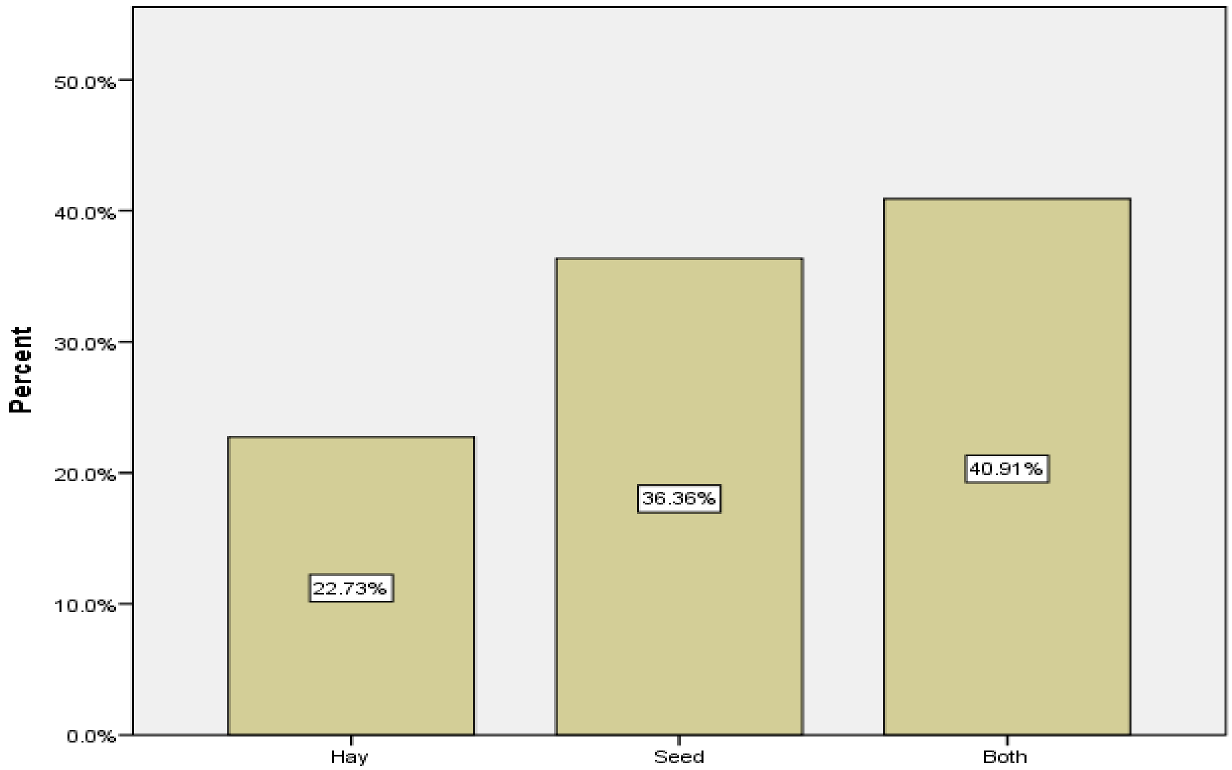

Figure 4: Pasture grass production

4.2.3. Pasture agronomic practices

Majority of the participants comprising of 56.3% did not practice any pasture management agronomic practices like weeding, manure and pesticide. While, 35.6% weeded their grasses and 6.9% applied manure as shown in figure 5.

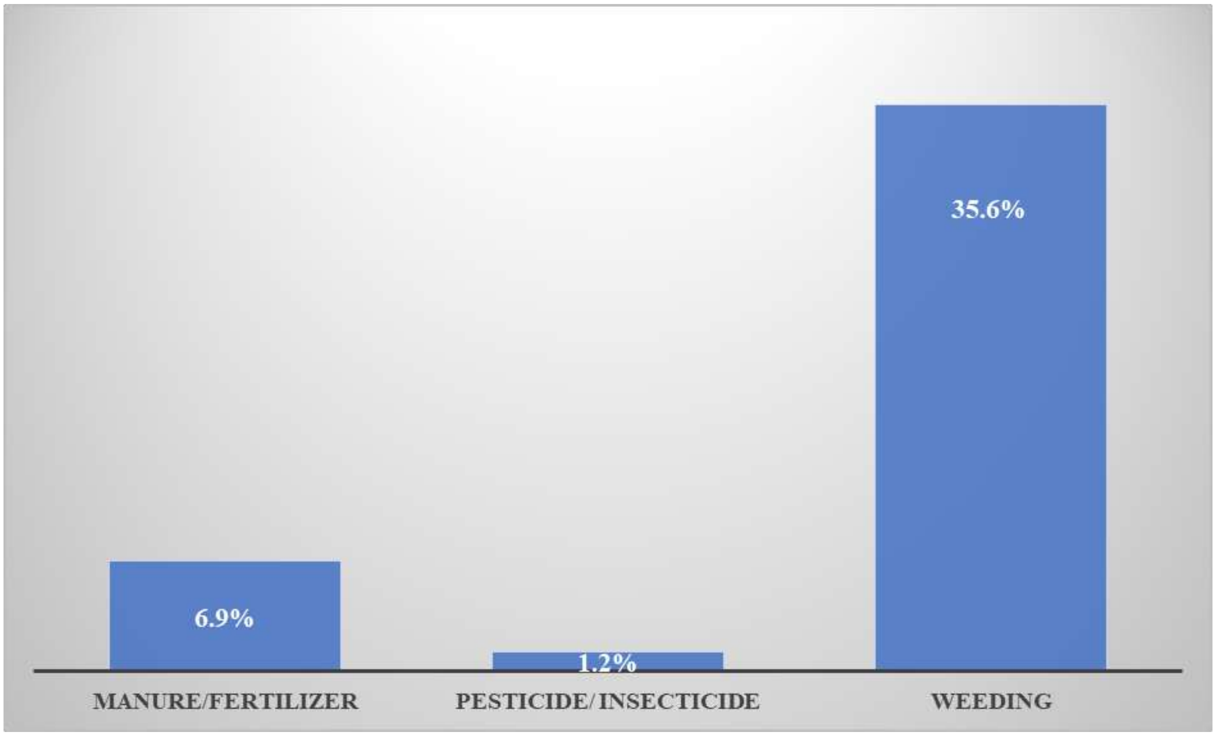

Figure 5: Pasture agronomic practices adopted

4.2.4. Pasture productions and revenues under different technologies

The study showed that farmers who weeded their farms had an increase in revenue than those who did not as shown below (Table 15). However, an independent t-test showed that there was no statistical difference between the yields obtained from farms that were weeded and those that were not at $p \leq 0.05$.

Table 15: Costs and benefits production per acre

Technology	Treatment	Mean (Kgs/season)	Costs 'Ksh'	Benefits 'Ksh'
Seed only	None weeded	85.0 ± 5.0	0.00 ± 0.00	59,500.00 ± 3,500.00
	Weeded	88.0 ± 15.9	6,026.40± 1,281.30	61,600.00 ± 11,130.00
	None weeded	43.7 ± 8.8	0.00 ± 0.00	728.33 ± 146.66
	Weeded	91.7 ± 11.5	6,026.40 ± 1,281.30	1,528.33 ± 191.66

Hay residue (Late harvested after seed)				
Grass hay	None weeded	192.0 ± 58.0	0.00 ± 0.00	3,200.00± 966.66
	Weeded	330.0 ± 0.0	6,026.40 ± 1,281.30	5,500.00 ± 0.00

Cost of kg of seed ksh700, cost of bale of hay (15kg) ksh250, cost of herbicide ksh900 per liter, man day ksh400 (2022)

The yields for farmers who practiced either seed bulking, hay pasture technologies or both were higher for farmers who weeded their farms than those who did not. However, the farmers who baled crop residuals as hay after seed harvesting had lower yields than farmers who produced hay only. This is due to foliage defoliation resulting from late hay harvesting. The research findings agree with Karimi et al., (2022) an on-farm study results that found out, weeding agronomic practice increased the potential for forage yields and profitability. As supported by Mganga (2010) study, there was an inverse relationship in biomass yields between weeds and established grasses across all phonological stages.

4.2.5. Differential analysis of pasture weeding

The results demonstrated that, although weeding was an important agronomic practice in grass biomass yield, the practice led to a negative net marginal value for weeding. That meant, it was non beneficial to weed to the farmers in the short run (3 years). This was put in consideration that the extra costs involved in weeding verses the extra gains that the farmer earned for weeding the former was higher (Table 17).

Table 16: Pasture grass production differential analysis

Technology	**Gain**	**Ksh**	**Loss**	**Ksh**
Seed only	Extra revenue	2,100.00	Revenue foregone	0.00
	Cost saved	0.00	Extra cost	6,026.40
	Net Gain/Loss	**(3,926.60)**		
Hay residue (Late harvested after seed)	Extra revenue	800.00	Revenue foregone	0.00
	Cost saved	0.00	Extra cost	6,026.40
	Net Gain/ Loss	**(5,226.40)**		
Hay only	Extra revenue	2,300.00	Revenue foregone	0.00
	Cost saved	0.00	Extra cost	6,026.40
	Net Gain/Loss	**(3,726.40)**		

The farmers who practiced either seed bulking, hay pasture technologies or both and chose to weed their farms had a consequent net marginal loss. The loss can be attributed to the significantly high weed density and biomass in the short term, thus missing the economic threshold. According to Davy, (2017), for perennial grasses species to maintain dominance, they will likely require frequent reseeding. Long-term goals of sustained dominant cover are best achieved after 3 years with high forage cover increasing production and preventing weed invasion.

Also, most of the farmers used manual techniques to control the weeds. The method used may not have been effective or efficient. A study done in Ethiopia on weed management in wheat, found out that herbicide weed control technique was more economically profitable to farmers than hand weeding twice for broadleaved weeds (Sareta, Worku, & Begna, 2016).

4.3. Logistic Regression Model

A binary logistic model between the adoption determinant factors was done to establish their influence on the farmers' choice to adopt or not adopt pasture technologies.

4.3.1. Model Summary

Table 17: Model fit

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	4.429[a]	.694	.959

R^2 value explained the measure of the proportion of the variation of the farmer adoption variable explained by the model. The Nagelkerke R^2 value was 0.959, indicating that 95.9% of the variation in the farmer pasture adoption status could be explained by the full model suggesting that predictions were highly reliable.

4.3.2. Variables in the Equation

Table 18: Variable significance

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Gender (Male)	24.618	8349.006	.000	1	.998	49167020995.544
	Age			.000	2	1.000	
	Youth (18-35)	-23.439	43967.137	.000	1	1.000	.000
	Middle (36-60)	-24.001	28774.987	.000	1	.999	.000
	Education			.000	3	1.000	
	Pre-Primary	7.181	56958.001	.000	1	1.000	1314.796
	Primary	5.612	49236.554	.000	1	1.000	273.651
	Secondary	2.576	27185.617	.000	1	1.000	13.149
	Pasture Technical Training	3.198	41110.579	.000	1	1.000	24.475

Access To Extension Support	19.296	15696.470	.000	1	.999	239946114.592
Land Resource (Acreage)	.648	.996	.423	1	.515	1.912
Constant	-6.336	46926.263	.000	1	1.000	.002

The variables age, level of education, pasture trainings, access to extension support and land resource had no significant influence to farmer adoption. Some of the study variable findings were in disagreement with Manyeki *et al.* (2013) research findings that age and farmer education level and Njarui *et al.* (2017) findings that access to extension support and land resource size had a significant influence on pasture production technology adoption.

CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATION

5.1. Summary

Weeds invasion into the rangelands causes loss of biodiversity, increased soil erosion, habitat loss, and decline in livestock carrying capacity. Range grass weeding was found to have a significant impact on productivity and marginal incomes of the farmers for all the grasses that were tested. Consequently, this will contribute to reduced livestock feed shortages, increased carry capacity, better farm incomes and standard of living, and concerted efforts by farmers to control weeds. The study aimed to examine the competitive interactions of three range grasses; *Chloris roxburghiana*, *Cenchrus ciliaris,* and *Eragrotis Superba* that are being promoted for adoption by agro-pastoralists to improve rangeland productivity in southern Kenya.

5.2. Conclusions

Weeds are a serious threat to newly established pastures if weed control measures are not effectively taken during the establishment phase of pastures. They make the rangeland restoration through reseeding challenging since they compete with grasses for already limited resources. Pasture growth and its morpho-ecological traits are key determinants in the grass's ability to out-compete weeds within its setting. Plant weeding helped plants to grow without competition for light, water and nutrients. Once weeds infest and establish into a pasture land, they can starve important grasses of crucial nutrients and water from the soil. Due to the nutrition distraction including nitrogen, potassium and phosphorous, can make the grasses susceptible to diseases and infestation by insects. Thus, lack of weeding reduces the yield performance of grasses as found on this research results. All the grass species that were weeded continuously, and periodically demonstrated a significant effect on grass cover, grass density, plant height and net dry matter biomass.

The results in this study demonstrated a significant difference in morpho-ecological characteristics in all the weeding regimes. Continuous and frequent weed management showed the highest grass pasture performance in all the parameters measured. None-weeding management demonstrated the least performances. A Pearson correlation analysis showed a positive inter-correlation between grass morpho-ecological parameters (grass cover, grass density, plant height, tiller density and grass biomass) and a negative inter-correlation between weed plant parameters and grass plant parameters. Good management and controlled grazing are necessary in maintaining a productive, weed-free stand in newly established pastures. Consistent weed control is effective as it cuts off the weed plant development and maturation.

An on-farm survey done in this research demonstrated that the pasture yields were higher for farmers who weeded their farms than those who did not in both seed and hay technologies. The marginal physical productivity (MPP) increased through investment in weeding and consequently an increase in biomass. However, the management practice led to a consequent net marginal loss within the short run. This meant that the marginal revenue generated from weeding range grasses was lower than the marginal cost incurred on weeding. The loss can be attributed to the significantly high weed density and low grass dominance cover in the short term, thus missing the economic threshold. However, according to Weir *et al.,* (2017), not all weeds are harmful considering livestock rely on diverse diets of woody plants, sedges, legume, grasses and forbs for high quality and quantity livestock and livestock products. For instance, ragweed (*Ambrosia* *pilostachya)* has a crude protein of 20% compared to common grasses. Instead of spending much on controlling such weeds, they should be considered to trade off the cost of protein supplements. Also, leguminous weeds tend are beneficial to the rangelands through nitrogen fixation, which enhances soil fertility and pasture growth.

5.3. Recommendations

According to the study experiment, the treatments that were weeded frequently, developed better morpho-ecological characteristics and consequent higher grass biomass yield. While, weeds density and cover increased with prolonged none-weeded periods. The study therefore recommends famers to adopt weed control of grasses to enhance their productivity. However, in the short run, the marginal cost for weed control for both hay and seed pasture grass production was higher than the marginal revenue derived from weeding at the prevailing market price and costs.

In this study, the palatability of the weed species controlled was not determined. Yet, the quality of some grass weeds can be comparable to that of pasture grasses. Management of these weeds may be of importance for the enhancement of the quality and quantity of the farmer pasture. Thus, the study recommends a further study on the cost benefit analysis of selective weeding of known non palatable and invasive weeds. The study also, studied respondents who had practiced pasture grass production (both hay and seed) for an average period of 3 years. Thus, more knowledge is required to establish on the cost effectiveness of grass weeding in the long run.

Based on the findings above, weed control practices have positive outcomes towards pasture productivity. Key stakeholders in rangeland management and livestock production can use the findings of this study as a basis to promote the adoption of weed control practices and pasture production by rangeland communities. To help farmers earn more revenue through pasture production, the national and county governments can provide relevant subsidies to ease cost of weed management and other inputs in production. Also, finding market and marketing of pastures and pasture seeds to reliable market is a great way to help farmers earn revenue through pasture production. Effective policies through the range management strategy are crucial in pasture and livestock production in rangelands. The ministry of agriculture and livestock development can help in formulating rangeland restoration mechanisms like grazing management, pasture reseeding, and proper range governance to enhance integrity of the rangeland livelihoods by enhancing productivity and ecosystem sustainability.

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