IMPACT OF ALTITUDE VARIATION AND GRASSLAND COMPOSIITION ON STEMBORER AND FALL ARMYWORM POPULATION IN MAIZE FARMS AND SURROUNDING GRASSES IN WESTERN KENYA DURING 2019-2020 RAIN SEASON

BY

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DECLARATION

I hereby certify that this thesis is my original research, and has not been presented in any university. The information contained herein was done by me and work from other sources is acknowledged by use of the references.

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DEDICATION

I dedicate this thesis to my lovely daughters, Joy Apondi and Whitney Monica. For always understanding me when I had to spend most time doing fieldwork and spending time away. Secondly, I dedicate this work to my sister, Mebo Nakhumicha and Peggy Knight for always being there for my daughters when I was away and taking good care of them and ensuring they were okay. Lastly, I dedicate my thesis to my lovely parents, William and Ruth Wafula. I thank them for their continuous prayers, support, and true love they have shown to me in life and ensuring I excel in my studies.

ABSTRACT

Grassland ecosystems adjacent to maize farms are often habitats for pests that pose significant risks to maize crops. Among these pests, lepidopteran stemborers and fall armyworm are the most detrimental, negatively impacting maize productivity. Although pests are known to thrive in grasslands, the influence of wild grassland composition on pest populations in maize fields and surrounding grasses across varying altitudes remains poorly understood especially in western Kenya. Given that altitude can significantly affect both plant and insect communities, studying this factor is crucial for developing effective pest management strategies. This study investigated the relationship between altitude and pest dynamics in maize farms and adjacent grasslands, focusing on four specific objectives, namely to: (i) assess the seasonal composition, distribution, and characteristics of grasses in grasslands near maize farms across four altitudes (low -1100 metres above sea level (masl); medium-1300 masl; high- 1500 masl; very high- 1700 masl) in western Kenya; (ii) examine the impact of altitude on grass species diversity and stemborer (*Busseola fusca* and *Chilo partellus*) and fall armyworm (*Spodoptera frugiperda*) populations across the four altitudinal zones; (iii) explore the influence of grass composition and characteristics on stemborer and fall armyworm populations in grasslands surrounding maize farms across the four altitudes; and (iv) investigate how surrounding grassland composition and characteristics affect stemborer and fall armyworm populations in maize farms across the four altitudes. The experimental design involved purposive sampling at four distinct sites of varying altitudes Mt. Elgon (very high elevation), Vihiga (high elevation), Homabay (medium elevation), and Lambwe (low elevation). Data were collected during the 2019 and 2020 short and long rain season respectively focusing on eight maize farms per site. Key parameters measured included grass diversity, percentage cover, species richness, and the abundance of stemborers and fall armyworms. Grass species were sampled using quadrats randomly placed in grasslands adjacent to maize farms, while inspecting 10 randomly selected maize plants from each farm assessed pest abundance. Environmental variables, including altitude, temperature, and soil moisture, were measured to contextualize grass and pest dynamics. Data analysis utilized the BiodiversityR package to rank grass species richness, Non-Metric Multidimensional Scaling (NMDS) for visualizing grass distribution, and Principal Component Analysis (PCA) to assess variable relationships. Spearman's correlation explored the influence of grass characteristics on pest abundance, while Tukey's HSD, linear regression, and Generalized Linear Models (GLM) evaluated altitude-pest dynamics relationships. Results showed a total of 55 grass species in 2020 versus 32 in 2019 across the four elevations. NMDS showed significant variation in grass composition by elevation ($P < 0.005$), with elevation affecting species composition more in 2020 (global $R^2 = 0.454$). Grass percentage cover was highest in Homabay in 2019, while Mt. Elgon showed increased cover in 2020. Lambwe displayed significantly higher grass fresh weight in both years. Additionally, fall armyworm abundance on maize farms correlated strongly with grass characteristics, especially grass cover, which negatively affected pest populations (Homabay $r_s = -0.93$, $P < 0.001$). These results underscored the need for pest management strategies that account for interactions between grassland ecology, pest biology, and agricultural landscapes, emphasizing the importance of grass species composition, diversity, and abundance in shaping pest populations.

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ACRONYMS, ABBREVIATIONS AND SYMBOLS

ICIPE - International Centre of Insect Physiology and Plant Ecology.

ES - Ecosystem Services

SA - Southern Africa

ACZs -Agro-climatic zones

SADs -Species Abundance distributions

PLS - Partial least squares

FAO - Food and Agriculture Organization.

FAW - fall armyworm

GLM - Generalized linear model.

LM - Linear model

CIMMYT - International Maize and Wheat Improvement Centre.

IITA - International Institute of Tropical Agriculture.

USDA-United States Department of Agriculture

FAS - Foreign Agriculture Service

IPM - Integrated Pest Management

FAOSTAT - Food and Agriculture Organization Corporate Statistical Database

R.h - relative humidity

DR Congo - Democratic Republic of Congo.

DWR – Dry weight rank

HSD post hoc tests - Honest Significance Difference post hoc tests.

Ln - Natural logarithms.

EOSDIS - Earth Observing System Data and Information System

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CHAPTER ONE

INTRODUCTION

1.1 Background to the study.

Maize (*Zea mays L.*) is Kenya's primary staple crop, essential for both food security and the livelihoods of rural communities, especially in the Western Kenya region. As population growth surges, the demand for maize intensifies, necessitating continuous increases in productivity to meet local consumption needs. However, maize farming faces persistent challenges, especially from pest infestations, which threaten crop yields and, by extension, food security. Among the most destructive maize pests are stemborers, primarily from the *Busseola fusca* and *Chilo partellus* species, and the invasive fall armyworm (*Spodoptera frugiperda*). These pests feed on maize leaves, stems, and reproductive parts, reducing yields and even causing total crop loss in severe infestations (De Groote et al., 2020). In Western Kenya, maize farms are often surrounded by wild grasslands, which serve as habitats for these pests, complicating efforts to control infestations (Cheruiyot et al., 2018).

Altitude plays a critical role in determining pest populations by influencing various climatic factors, such as temperature, rainfall, and humidity (Fleishman et al., 2006). In Kenya, altitude varies significantly across regions, creating distinct agro ecological zones that affect maize pest distribution. For instance, stemborer populations tend to be denser at mid-altitudes (1,500–2,000 meters), where temperature and humidity levels provide optimal conditions for pest survival and reproduction. At higher altitudes, pest populations are generally lower due to cooler temperatures, while in low-altitude zones; warmer climates favor species like *Chilo partellus* and the fall armyworm (Prasifka et al., 2011); Ritmeijer et al., 2011). Despite this established relationship, studies specific to Western Kenya remain limited, and there is a need to understand how altitude-specific climate variations in this region affect stemborer and fall armyworm populations.

Grasslands occupy a significant portion of Kenya’s landscape and are fundamental to the ecology of pests affecting maize. In Western Kenya, grasslands are predominantly composed of various species from the *Poaceae* family, which form dense cover around agricultural fields. These wild grasses are known to be primary hosts for pests, as they provide refuge and food sources during non-cropping seasons, facilitating pest survival and allowing stemborer larvae to diapause, or enter a period of dormancy (Mwalusepo et al., 2018). In a study by (Haile & Hofsvang, 2001), stemborer larvae densities were found to vary across different altitudinal zones in Kenya, with *Busseola fusca* predominating at higher elevations and *Chilo partellus* at lower ones, illustrating how altitude influences pest populations across grassland and maize ecosystems.

The relationship between grassland composition and pest population dynamics in maize fields is of particular importance in Western Kenya, where maize farms are often adjacent to natural grasslands. The grass species composition can directly affect the abundance of stemborers and fall armyworms. Some grass species provide favorable conditions for pest egg-laying and larval development, while others may discourage pest colonization due to tough foliage or chemical defenses (Tscharntke et al., 2005; Asplund et al., 2009). For example, certain grasses with high nutrient content or softer tissue structures can support higher densities of stemborers, while others that produce deterrent chemicals may limit pest populations. This relationship between grass species and pest density, however, has not been thoroughly investigated in the Western Kenyan context, where altitude variations further complicate these interactions.

Western Kenya's grassland composition influences the pest pressures on maize fields not only by providing habitat but also by affecting natural pest control processes. Grasslands that support diverse flora and fauna can promote biological pest control by hosting natural predators and parasitoids, which help to regulate stemborer and fall armyworm populations (Khan et al., 2007). Studies from other regions have shown that certain grass species attract parasitoid wasps that prey on stemborer eggs and larvae, contributing to pest suppression in nearby maize fields (Ndemah et al., 2003b). However, current knowledge on the extent to which grasslands in Western Kenya enhance biological control is limited, particularly concerning variations in grass species and altitudinal zones.

Given the severe economic losses attributed to pest infestations, numerous control strategies have been proposed, including chemical pesticides, intercropping with non-host plants, and crop rotation (Midega et al., 2018; Sisay et al., 2018). Among these, the push-pull method a practice involving the planting of pest-repellent plants alongside attractive trap crops around maize fields has shown promise in reducing stemborer infestations (Muyekho et al., 2003; Gurr et al., 2004). Although the push-pull technology has been widely researched, its effectiveness specifically in grasslands surrounding maize farms in Western Kenya requires further exploration. This is especially relevant in varying altitudes where the interaction between pest, crop, and grass species could differ significantly from findings in other regions.

The relationship between grass species composition and pest population dynamics in maize farms across varying altitudes in Western Kenya remains underexplored. A comprehensive understanding of how altitude influences the composition of grass species and, in turn, affects stemborer and fall armyworm populations could be key to developing ecologically sound, sustainable pest management strategies. Specifically, identifying grass species that either deter pests or support natural predators may help refine practices like push-pull technology and habitat management, making them more effective in this diverse and ecologically complex region. This study, therefore, seeks to investigate the impact of altitude variation and grassland composition on the population of stemborers and fall armyworms in maize farms and adjacent grasslands in Western Kenya. By addressing this knowledge gap, the study will contribute to region-specific pest management strategies, ultimately aiding in the protection of maize crops and enhancing food security across the region.

1.2 Statement of problem

The maize crop in Western Kenya faces persistent threats from stemborer and fall armyworm infestations, which result in significant yield losses and food insecurity in a region heavily reliant on maize as a staple. Grasslands surrounding maize farms, particularly those composed of wild grasses, serve as habitats and breeding grounds for these pests, facilitating pest survival during non-cropping seasons. Altitude variations across Western Kenya further complicate pest management, as altitude influences climate conditions, which in turn affect pest distribution, abundance, and behavior.

Despite the critical impact of these pest populations, there is limited research on how specific grass species in these grasslands, combined with altitude-driven climate factors, influence the population dynamics of stemborers and fall armyworms in maize farms. Current pest management strategies, such as push-pull technology and intercropping, lack tailored insights into how these altitude and grassland composition factors might affect pest control effectiveness in Western Kenya's diverse landscapes.

This study, therefore, seeks to address the knowledge gap by investigating the impact of altitude variation and grassland composition on the populations of stemborers and fall armyworms in maize farms and adjacent grasslands in Western Kenya during 2019 and 2020. Findings from this study will contribute to more targeted and ecologically sustainable pest management strategies, specifically designed for the unique environmental conditions of Western Kenya.

1.3 Justification of the study

Maize is a crucial staple crop in Western Kenya, providing food security and livelihoods for the local population. However, maize production in this region is increasingly threatened by stemborers and fall armyworms, which cause significant yield losses and exacerbate food insecurity. Current control methods, including chemical pesticides, push-pull technology, and intercropping, have shown mixed results in managing these pests effectively. This is largely due to the variability in pest populations influenced by altitude and surrounding grassland composition, which are unique features of Western Kenya's landscape. Understanding how altitude variation and grassland composition affect pest dynamics is essential for enhancing pest management in this region.

Previous studies on stemborer and fall armyworm populations in Kenya have provided valuable insights, but there is a notable gap in knowledge specific to Western Kenya. This area is characterized by diverse altitudinal gradients and extensive grasslands, which likely affect the behavior, distribution, and abundance of these pests differently than in other regions. The study aims to provide data-driven insights into how these factors interact to influence pest populations, especially during off-cropping seasons when pests persist in surrounding grasslands and reinvade maize fields upon planting.

By focusing on the impact of altitude and grassland composition on pest populations, this study seeks to inform ecologically sustainable pest management strategies that are tailored to Western Kenya's environmental and agricultural context. The findings will contribute to developing adaptive pest control approaches that not only protect maize yields but also promote biodiversity and ecosystem resilience in the region. Furthermore, this study aligns with the goals of enhancing food security and supporting smallholder farmers by reducing reliance on chemical pesticides and encouraging practices that leverage natural ecological processes for pest control.

1.4 Objectives

1.4.1 General Objective

To investigate the impact of altitude variation and grassland composition on the populations of stemborers (*Busseola fusca* and *Chilo partellus*) and fall armyworms (*Spodoptera frugiperda*) in maize farms and the surrounding grasslands in Western Kenya during the years 2019 and 2020.

1.4.2 Specific objectives

(i) To assess the seasonal composition, distribution, and characteristics of grasses in grasslands near maize farms across four altitudes (low -1100 meters above sea level (masl); medium-1300 masl; high- 1500 masl; very high- 1700 masl) in western Kenya.

(ii) To examine the impact of altitude on grass species diversity and stemborer (*Busseola fusca* and *Chilo partellus*) and fall armyworm (*Spodoptera frugiperda*) populations across the four altitudinal zones.

(iii) To explore the influence of grass composition and characteristics on stemborer and fall armyworm populations in grasslands surrounding maize farms across the four altitudes.

(iv) To investigate how surrounding grassland composition and characteristics affect stemborer and fall armyworm populations in maize farms across the four altitudes.

1.5 Hypotheses

1. There is no significant difference in the composition, distribution, and characteristics of grasses in grasslands adjacent to maize farms across four varying altitudes in Western Kenya during the short rain season of 2019 and the long rain season of 2020.

2. Altitude variation has no significant effect on grass species diversity and the populations of stemborers (*Busseola fusca* and *Chilo partellus*) and fall armyworms (*Spodoptera frugiperda*) in the selected altitudinal zones of Western Kenya.

3. Grass composition and characteristics do not significantly influence the populations of stemborers and fall armyworms in the grasslands surrounding maize farms at four different altitudes in Western Kenya.

4. Grass composition and characteristics have no significant effect on the populations of stemborers and fall armyworms within maize farms located at four varying altitudes in Western Kenya.

CHAPTER TWO

LITERATURE REVIEW

2.1 Grass composition, distribution, and characteristics of grasses in grasslands adjacent to maize farms across four varying altitudes in Western Kenya.

Grasslands represent a crucial part of global biodiversity, providing essential ecosystem services that sustain both natural ecosystems and human livelihoods. These services include soil stabilization, water regulation, and carbon sequestration, all of which contribute to environmental stability and resilience (Hoekstra et al., 2005). This study titled Impact of Altitude Variation and Grassland Composition on the Population of Stemborer and Fall Armyworm on Maize Farms and Grasses Surrounding the Farms in 2019 and 2020 seeks to understand how altitude and grassland ecology influence pest populations in Western Kenya, with a specific focus on stemborer (*Busseola fusca* and *Chilo partellus*) and fall armyworm (*Spodoptera frugiperda*). In Western Kenya, these pest populations, along with grass species composition and abundance, are shaped by various ecological factors, including altitude, which affects microclimate conditions like temperature and rainfall.

Recent research from Western Kenya highlights that altitude can affect both plant diversity and pest prevalence, with higher altitudes typically associated with cooler temperatures and diverse plant species, which can indirectly affect pest abundance. Studies by Akwee et al. (2020) demonstrate how altitude and related microclimatic conditions in Western Kenya influence grass species diversity, which, in turn, may affect pest-host interactions in adjacent maize fields. Additionally, research by Kioko, Warui, and Seno (2012) reveals that grassland fragmentation in Kenya's highlands leads to decreased biodiversity, disrupting ecological roles that natural grasslands provide, such as habitat for pest predators.

Grasslands adjacent to maize fields play a crucial role in either attracting or repelling maize pests, depending on the grass species and density. For instance, research indicates that diverse and densely vegetated grasslands can suppress fall armyworm and stemborer populations by creating a habitat unfavorable to pests or by supporting the predators of these pests (Akwee et al., 2020; Kioko et al., 2012). Additionally, studies on agricultural landscapes by Nyang'au et al. (2018) and Okeyo et al. (2017) in Western Kenya report that altitude and biodiversity in surrounding grasslands significantly influence pest pressures on crops, with higher pest abundances noted at lower altitudes due to warmer conditions and altered grassland composition. These findings emphasize the need for sustainable land management practices that consider both altitude and grassland health to mitigate pest pressures on maize farms effectively. Incorporating altitude-specific conservation strategies can, therefore, enhance both pest management and biodiversity conservation, benefiting local agriculture and ecosystem resilience.

2.1.1 Grass Composition and Zonal Variability across Western Kenya

Grass composition in Western Kenya reflects both the specific environmental pressures of this region and the diversity of ecological zones found within Kenyan grasslands. The grass species dominant in Western Kenya's grasslands are adapted to local climate, altitude, and soil conditions, with several species exhibiting high resilience to environmental stresses like grazing and periodic fires.
The highland grasslands in the highland areas of Western Kenya, where temperatures are cooler and rainfall is more abundant, *Pennisetum clandestinum* (Kikuyu grass) is a predominant species. This grass is native to the East African highlands and is well suited to the region’s climatic conditions, exhibiting rapid growth and resilience under heavy grazing pressure (Anderson et al., 2007). As a high-productivity species, Kikuyu grass provides a dependable food source for grazing livestock and plays an essential role in local agricultural practices. It has become a valuable component of pastureland in Western Kenya, reflecting the interaction between native flora and human land-use patterns.

The adaptability of Kikuyu grass to cool, moist conditions highlights its ecological role as a stabilizing species within the highland grassland ecosystem. With its deep root system, Kikuyu grass helps prevent soil erosion, an essential function in the hilly terrain of Western Kenya, where heavy rainfall can lead to significant erosion risks (Smith et al., 2014). This role in soil stabilization supports both biodiversity conservation and agricultural productivity, illustrating the multiple ecological benefits provided by native grasses in the region.
In the semi-arid savannah regions of Western Kenya, dominant species include *Themeda triandra* (red oat grass) and *Hyparrhenia rufa* (thatch grass), both of which are well suited to withstand periodic fires and intense grazing. *Themeda triandra*, a native grass species in the

savannah grasslands of Western Kenya, exhibits adaptations like rapid regrowth after fire or grazing, which helps maintain ecological stability by supporting cycles of disturbance and recovery. Studies show that this resilience to fire plays a critical role in controlling woody plant encroachment, thus preserving the biodiversity of savannah ecosystems (Otieno et al., 2020). Themeda's tolerance to nutrient-poor soils also allows it to flourish in challenging conditions where soil fertility limits other species' survival (Kinyua et al., 2018).

Many grasses in Western Kenya's savannahs, including *Themeda triandra* and *Hyparrhenia rufa*, follow the C4 photosynthetic pathway, an adaptation that enhances photosynthetic efficiency in high temperatures and bright light by conserving water during carbon dioxide capture (Wang et al., 2022). This pathway is particularly advantageous in arid environments, as it allows these species to sustain high productivity even under water-limited conditions. Research confirms that this C4 mechanism not only supports grass survival but also boosts primary production, essential for herbivores relying on these grasslands for forage (Nzila et al., 2021). Consequently, C4 grasses contribute significantly to the resilience of Western Kenya's ecosystems, as well as to the economic stability of local communities' dependent on livestock grazing (Wasonga et al., 2020). These adaptations underscore the importance of preserving C4 grass-dominated savannahs, which sustain both ecological and socioeconomic systems in the region.

2.1.2 Sampling Strategies for Grass Composition

Sampling strategies for studying grass composition in Western Kenya's diverse grasslands require careful adaptation due to environmental factors like rainfall, topography, and soil type that drive unique vegetation distribution patterns. Despite advancements in global sampling methodologies, research addressing their applicability within Kenya's highland and savannah grasslands remains limited.

Random sampling methods, often conducted with quadrats, help capture plant diversity in regions with variable spatial distributions (Ong'amo et al., 2019). However, in Western Kenya, studies have shown that random sampling may underrepresent certain species, particularly rare or dominant types, due to inconsistent vegetation density (Otieno et al., 2020). Systematic sampling, in which samples are collected at fixed intervals, can yield consistent, repeatable data, especially in savannah regions with sparse grass cover (Wanjiku et al., 2020). While effective in low-density areas, systematic sampling may overlook high-diversity zones, raising questions about its efficiency in capturing local biodiversity within Kenya’s complex grassland ecosystems (Ong'amo et al., 2019).

Grid sampling, applied to areas with environmental gradients, is advantageous in Western Kenya’s highland zones for studying changes in grass composition across altitude and soil type variations. However, research specifically evaluating grid sampling within this region is sparse (Maina et al., 2019). Meanwhile, stratified sampling, which divides landscapes based on ecological features, allows for detailed surveys within Western Kenya’s varied landscapes, such as riparian and highland zones (Mwangi et al., 2018; Tiedje et al., 1983). This approach is effective in capturing grassland biodiversity across ecologically distinct zones but remains underexplored in Kenyan studies, revealing a gap in localized research.

This study highlights the need for tailored sampling strategies in Western Kenya’s unique grasslands, where diverse environmental gradients and habitat types necessitate flexible approaches for biodiversity assessment and conservation planning. Random sampling techniques, such as the use of quadrats, are commonly employed in Kenyan grasslands where vegetation exhibits random spatial variation. This method helps to capture representative data across heterogeneous landscapes, where plant distribution may not follow a clear pattern. In Western Kenya, random sampling can effectively capture diverse grass species composition, especially in grasslands with mixed vegetation types. However, studies have shown that random sampling can be limited in areas with low vegetation density or where specific species are sparsely distributed, potentially missing rare species or under-representing dominant grass types (Hobbs et al., 2007; Tiedje et al., 1983). There is thus a research gap in assessing the extent to which random sampling, as traditionally applied, effectively reflects grass species diversity in regions like Western Kenya, where unique local conditions may call for more approaches that are refined.

In areas where vegetation is sparse or unevenly distributed, systematic sampling is often preferred. In this method, quadrats are placed at fixed intervals, providing a structured approach to capture vegetation composition across broader areas and enabling consistent measurements over time (Whalley & Hardy, 2000a). Systematic sampling is particularly relevant in Western Kenya's savannah regions, where grass cover may be sparse or interrupted by woody encroachment and bare soil patches. While systematic sampling offers the advantage of repeatability and can track changes in vegetation cover, it may miss areas of high species richness, as the fixed-interval approach does not adapt to localized ecological variation. Studies specific to Western Kenya that evaluate the accuracy of systematic sampling in detecting rare species and capturing floristic variation are currently limited, highlighting a need for targeted research to address this gap.

Fixed grid sampling, another useful strategy, places sampling points within a predetermined grid, which helps capture grass species composition in ecosystems characterized by distinct spatial patterns, such as patches or gradients. In Kenyan grasslands, particularly in Western Kenya’s highland regions, grid sampling has potential applications for assessing species composition across gradients in altitude and soil type. Grid sampling allows researchers to detect variations along environmental gradients effectively, providing insight into how grass species change across these gradients (Ong’amo, Rü, et al., 2006). However, existing studies have rarely focused on applying fixed grid sampling in Western Kenya, leaving a knowledge gap regarding how grass species distribution responds to such environmental gradients within this region's unique topographical context.

Stratified sampling divides the landscape into distinct strata based on ecological or vegetation patterns, allowing for intensive sampling within specific zones. This method can be particularly useful in capturing diversity within highly heterogeneous landscapes, as it enables researchers to focus on particular grassland types or environmental conditions (Tiedje et al., 1983). In Western Kenya, stratified sampling could enhance accuracy by focusing on distinct ecological zones, such as savannah, highland grasslands, and riparian zones. This method has been effective in other biodiversity-rich regions, and its application could potentially address the challenges of accurately capturing diversity in areas where grass species composition changes significantly over small spatial scales. However, current research lacks a systematic approach to stratified sampling specific to Western Kenya’s grasslands, leaving a research gap on the efficacy of stratified sampling in capturing the biodiversity of these highly varied environments.

While various sampling strategies have been applied in Kenyan grasslands, their application within the context of Western Kenya’s diverse ecosystems remains limited. Specific research on the efficacy of sampling techniques tailored to Western Kenya’s unique environmental gradients, such as highland slopes, riverine areas, and semi-arid regions, is scarce. Studies that assess the effectiveness of existing sampling methods in accurately capturing grass species diversity, particularly in capturing rare or endemic species within the grasslands of Western Kenya, are needed to inform future ecological studies and conservation efforts.

Given the ecological importance of Western Kenya's grasslands in supporting both biodiversity and local livelihoods, filling these research gaps is critical for the development of effective conservation strategies. Addressing these gaps require targeted studies that evaluate and compare sampling techniques, providing data-driven recommendations that inform biodiversity assessments and conservation planning specific to this ecologically rich but understudied region.

2.1.3 Grass Species Richness and Diversity

Grass species richness, defined by the number of unique species in a given area, is an essential measure of ecosystem resilience and biodiversity. Kenyan grasslands exhibit diverse species richness and composition due to environmental factors like soil composition, rainfall, and temperature variations. Altitude, particularly in highland zones, creates specific microclimates that support unique grass species adapted to cool, high-humidity environments (Muturi et al., 2020). This altitudinal variation in environmental conditions fosters distinctive grass assemblages, forming a complex mosaic of biodiversity that sustains both ecological and agricultural functions (Ngugi & Nyariki, 2020).

Diversity metrics like the Shannon and Simpson indices are widely used to quantify species richness and assess ecosystem health. The Shannon index considers both richness and species evenness, offering insights into species abundance, while the Simpson index emphasizes dominance within the species community. These indices facilitate multi-scale assessments of biodiversity, covering alpha (local diversity), beta (diversity across habitats), and gamma (landscape-level diversity) metrics, crucial for understanding species distribution and resilience in the face of environmental changes (Otieno et al., 2019).

In Western Kenya, species such as *Themeda triandra* and *Hyparrhenia rufa* in savannah zones demonstrate drought and fire resilience, whereas highland regions feature *Pennisetum clandestinum* adapted to cooler, wetter conditions. Coastal areas also host species like *Cynodon dactylon*, suited to saline environments (Mwangangi & Wambua, 2019). This spatial variability in species diversity underscores the ecological importance of maintaining a rich mix of native species across the country, especially for ecosystem services like soil stabilization and carbon sequestration (Otieno et al., 2020).

The current gap in research specific to Western Kenya limits the understanding of the impacts of environmental gradients and land use on grass species richness. The use of diversity metrics in this region could identify biodiversity hotspots and detect shifts in species composition due to environmental pressures, supporting targeted conservation strategies (Maina et al., 2020). Filling this research gap is essential for informing management practices that preserve both species diversity and ecosystem resilience in Kenya's grasslands.

The varied climates and ecological characteristics across Kenya's grassland regions create an intricate web of grass species diversity that is critical for ecosystem functioning. Grasslands not only provide forage for wildlife and livestock but also play roles in soil stabilization, nutrient cycling, and carbon storage. However, these benefits hinge on maintaining a rich diversity of native species, which are often threatened by factors such as land conversion, invasive species, and overgrazing. Research on species richness and diversity across these regions is limited, particularly in understudied areas like Western Kenya, where climatic and geographical characteristics contribute to distinct grass communities.

Diversity metrics like the Shannon and Simpson indices offer valuable insights for conservation and management by revealing patterns in species abundance and richness that reflect ecosystem health. These metrics are instrumental in identifying biodiversity hotspots and areas with high species endemism, guiding decisions about which areas to prioritize for conservation efforts. By measuring alpha, beta, and gamma diversity, ecologists can detect changes in species composition at different scales, which is essential for monitoring ecosystem dynamics over time.

In Kenyan grasslands, especially in Western Kenya, the application of these diversity metrics could aid in understanding the pressures on local grass species and provide a foundation for adaptive management strategies. Despite their potential, comprehensive studies that utilize these metrics to assess grass diversity across Kenya's grasslands are rare, particularly in areas such as Western Kenya, where the environmental variability supports a unique and possibly fragile grass species assemblage. Filling this research gap would enhance the understanding of species diversity dynamics, helping to develop targeted conservation strategies that address regional biodiversity needs.

There is limited research on grass species richness and diversity specific to Western Kenya, a region that features unique climatic and geographic variations that likely contribute to distinct grassland communities. While diversity indices are widely used in global grassland research, their application to Western Kenya remains minimal, leaving a gap in knowledge about the specific diversity patterns in this ecologically significant area. Furthermore, the impact of environmental gradients, land-use practices, and climate variability on species diversity within Western Kenya's grasslands is poorly understood.

Current research often aggregates data on Kenyan grasslands without distinguishing regional variations, which limits the accuracy and relevance of conservation strategies. Detailed studies that investigate the diversity of grass species in Western Kenya using standardized diversity indices are essential for filling these knowledge gaps. Such research could provide critical insights into the resilience and vulnerability of grass species in Western Kenya, informing conservation practices that preserve both species richness and ecosystem functions.

2.1.4 Grassland Disturbance and Management

Both human-induced and natural disturbances significantly influence grassland ecosystems, shaping their structure, species composition, and ecological functions. Grazing, one of the most prevalent disturbances in grasslands, impacts vegetation structure and composition by selectively removing plant biomass and introducing livestock dung, which alters nutrient availability (Foley et al., 2011). The effects of grazing extend to trampling, which compacts soil and affects water infiltration, leading to shifts in species composition as disturbance-tolerant species become more dominant. This shift can reduce plant diversity and alter ecosystem functioning by favoring certain grasses over others (Ali et al., 2018).

Management interventions, including fertilization, mowing, and plowing, are also known to reshape grassland ecosystems. Fertilization, for example, tends to promote the growth of fast-growing, nutrient-responsive species, often at the expense of less competitive species, leading to changes in species abundance and a decrease in overall diversity (Simons et al., 2015). Mowing and plowing similarly affect species composition and abundance, particularly by removing biomass and disrupting root systems, which may favor disturbance-resilient species while suppressing more sensitive, native flora. These changes can affect ecosystem services such as soil fertility, carbon storage, and habitat provision for wildlife.

In Kenya, traditional grazing practices have long been integral to the ecological stability of grasslands, particularly in areas where pastoralism is a primary livelihood. In regions such as the semi-arid savannahs, grazing by livestock is regulated by seasonal movements and rotational grazing patterns, which help prevent overuse of specific areas and support species resilience by allowing grasses time to recover. However, as land-use pressures increase, particularly due to agriculture and urban expansion, the delicate balance between sustainable use and conservation is increasingly threatened (Schwander et al., 2016). Traditional practices are being compromised as grazing areas shrink, leading to overgrazing in remaining patches and contributing to soil degradation, loss of species diversity, and the spread of invasive species.

While studies on grassland disturbances in Kenya exist, much of the research has been concentrated in well-studied regions such as the Maasai Mara and Samburu. However, the grasslands of Western Kenya have received limited attention, even though they are subject to unique ecological pressures and land-use dynamics that differ from other parts of the country. Western Kenya's grasslands are influenced by a combination of agricultural expansion, human settlement, and small-scale grazing practices, all of which impose specific types of disturbances on grass species composition and ecosystem stability. The impact of these factors remains underexplored, creating a research gap in understanding how different disturbance types influence grassland resilience and biodiversity in this region.

Additionally, while the effects of grazing have been relatively well-documented, other management practices such as the use of fertilizers, small-scale plowing, and crop-livestock integration in Western Kenya require further study. These practices can affect soil nutrient cycles, water availability, and species competition, influencing the long-term viability of grassland species. For example, studies from other regions have shown that fertilization and plowing can lead to nutrient imbalances and soil degradation (Simons et al., 2015). However, specific insights into how these effects play out in the distinctive ecological context of Western Kenya are lacking.

Moreover, research on the interactions between native grassland species and invasive species in response to disturbances in Western Kenya is minimal. While invasive species like *Lantana camara* and *Parthenium hysterophorus* are known to encroach on disturbed grasslands, studies are needed to understand how their presence alters local species dynamics, soil health, and nutrient availability. Such research could guide effective management interventions to control invasive species and maintain native biodiversity.

Overall, addressing these research gaps in Western Kenya would provide critical insights for balancing conservation and sustainable use in grassland management. Comprehensive studies on disturbance types, their ecological impacts, and adaptive management strategies are needed to develop tailored approaches that preserve biodiversity, enhance ecosystem services, and support the livelihoods of communities' dependent on these grasslands.

2.1.5 Analytical Approaches for Ecological Data

The seasonal composition and distribution of grasses in grasslands adjacent to maize farms are pivotal for effective pest management strategies. Analytical methods like Principal Component Analysis (PCA) are essential in simplifying complex datasets and revealing patterns in grass species distribution across different altitudes. For instance, research indicates that PCA can effectively capture how environmental variables such as altitude and precipitation influence grass composition (He et al., 2021; Zeng et al., 2020). Applying PCA to seasonal data helps to understand fluctuations in grass diversity and their implications for pest dynamics.

Non-Metric Multidimensional Scaling (NMDS) complements PCA by visualizing community composition, allowing researchers to better understand how environmental factors influence grass distribution in relation to pest habitats. NMDS is valuable for illustrating how seasonal changes affect species composition in grasslands (Duarte et al., 2021). By leveraging NMDS, researchers can gain insights into how seasonal dynamics of grass composition impact maize fields in Western Kenya.

2.2 Impact of altitude variation on grass species diversity and the populations of stemborers (*Busseola fusca* and *Chilo partellus*) and fall armyworms (*Spodoptera frugiperda*) in the selected altitudinal zones of Western Kenya.

2.2.1 Influence of Altitude on Grass Distribution

Altitude has a significant impact on environmental conditions, with temperature decreasing by approximately 6.5°C for every 1,000 meters of elevation gained (Barry & Chorley, 2009). This temperature gradient, along with changes in precipitation, creates unique ecological niches across elevations that shape the distribution and diversity of grass species. At higher elevations, greater precipitation and cooler temperatures often lead to distinct vegetation compositions adapted to withstand these fluctuating conditions (Ahrens, 2011). In Kenya's highland regions, this altitudinal gradient is a major driver of grass species diversity, as grasses in these areas must tolerate a range of humidity, precipitation, and temperature levels (Grace, 1987).

In the highland regions of Western Kenya, altitude-driven variations create diverse habitats that support a rich composition of grass species. The high altitudes of the Mau Escarpment, Cherangani Hills, and other upland areas, which feature a mix of cooler temperatures, consistent rainfall, and varying soil types, influence these grasslands. This diversity supports unique grass species adapted to the cooler and often wetter highland climate. Common grass species in these areas include *Pennisetum clandestinum* (Kikuyu grass) and *Pennisetum purpureum* (elephant grass), which are adapted to moist, nutrient-rich soils and play critical roles in grazing systems and soil stabilization (Smith et al., 2014).

2.2.2 Altitudinal Influence on Grass Species Composition in Western Kenya

Despite these general insights, the grassland ecosystems in Western Kenya remain understudied relative to more prominent regions like the central highlands and Rift Valley. While highland grasslands in central Kenya have been, extensively analyzed, limited research has specifically focused on how altitudinal gradients in Western Kenya affect grass distribution and species composition. The region's unique altitude-induced climate patterns, coupled with its distinctive topographical features, likely contribute to variations in species composition that differ from those observed in other parts of Kenya.

For instance, studies have shown that at higher elevations, grasslands are often characterized by lower species richness but higher abundance of species specially adapted to cooler, wetter conditions (Whittaker & Whittaker, 1972). However, this pattern may vary in Western Kenya due to its complex landscape, which includes both steep slopes and flatter terrains, each providing different microhabitats and influencing grass distribution. More research is needed to understand how these microhabitats impact grass species richness, as well as how species composition might shift across different elevations and slope gradients in Western Kenya.

2.2.3 Adaptations to Altitude-Driven Environmental Conditions

At high altitudes, grasses in Western Kenya may develop adaptations to withstand colder temperatures and increased rainfall. For instance, the presence of high-altitude adapted species such as *Pennisetum clandestinum* (Kikuyu grass) in Western Kenya’s highlands indicates that grasses in these regions might employ strategies like increased root biomass for water retention or enhanced nutrient storage to cope with seasonal temperature drops and moisture availability. However, detailed studies focusing on the specific adaptations of highland grasses in Western Kenya are sparse, presenting a clear research gap in understanding the physiological and morphological responses of these species to altitudinal influences.

2.2.4 Conservation and Management Implications in Western Kenya's Highland Grasslands

Understanding the influence of altitude on grass distribution is critical for conservation and management strategies, particularly in highland grasslands that face anthropogenic pressures such as agricultural expansion and livestock grazing. While studies have shown that high-altitude grasslands are highly sensitive to changes in temperature and moisture availability (Ahrens, 2011), limited research has explored how these pressures affect the unique grass species of Western Kenya's highlands. Additionally, as climate change brings about shifts in temperature and precipitation patterns, there is a growing need to understand how these changes might alter the altitudinal distribution of grass species, particularly in regions like Western Kenya where grassland resources are integral to local livelihoods.

More localized studies are essential to document the specific impacts of altitude on grass species composition and resilience to climate variability in Western Kenya's highlands. Filling this research gap will help inform sustainable land-use practices, conservation planning, and strategies to preserve the ecological balance and biodiversity of these highland grasslands.

2.2.5 Altitude and Pest Distribution

Altitude has a profound impact on the distribution of agricultural pests in Kenya, influencing pest behavior, reproduction rates, and population dynamics. This altitude-driven distribution is especially relevant in managing pest populations of species like stemborers (*Busseola fusca* and *Chilo partellus*) and fall armyworms (*Spodoptera frugiperda*). In mid-altitude regions (1,600–2,200 meters), *Busseola fusca* is a stemborer species particularly suited to cooler, humid environments has been observed to thrive due to these favorable climatic conditions (Ritmeijer et al., 2010). Conversely, lower-altitude zones (below 1,500 meters), characterized by higher temperatures, are more suitable for *Chilo partellus*, which benefits from the warmth and availability of host plants (Hailu et al., 2018). Fall armyworms, which have a broader altitudinal range, can establish populations in both lowland and mid-altitude zones, where warmer temperatures aid their rapid reproduction (Hailu et al., 2018).

Understanding these altitudinal distributions is crucial for developing localized pest control strategies that address the specific needs of each region. Pest control efforts that consider these altitudinal variations are better positioned to effectively manage pest populations and mitigate the economic impact of infestations. However, while much is known about the general altitudinal distribution of these pests, significant research gaps remain, particularly in the highland regions of Western Kenya, where unique environmental conditions may shape pest behavior differently than in other regions.

One key area of research that remained underexplored in Western Kenya is the physiological adaptations enabling pests to survive across varying altitudes. Pests like *Busseola fusca* and *Chilo partellus* display resilience across altitudinal gradients, yet little is known about the specific adaptations that allow them to thrive in different temperature, humidity, and oxygen levels. Additionally, factors like host plant availability and interspecies competition may vary across altitude, influencing pest population dynamics. These ecological interactions are particularly relevant in Western Kenya, where mid- to high-altitude zones have unique climatic and topographical conditions that could affect pest physiology and adaptation. A better understanding of these adaptations is crucial for developing altitude-specific pest management practices that target pest vulnerabilities effectively.

Climate change presents an emerging challenge, as shifts in temperature and precipitation may drive pests to expand into higher altitudinal zones, potentially altering the ecosystem balance and increasing pest pressures in new regions. For instance, warming temperatures may allow *Chilo partellus* to colonize higher altitudes where it has previously been less prevalent. This shift could disrupt the existing dynamics of pest populations, affecting both local agricultural practices and pest control strategies. In Western Kenya, where highland agriculture is essential for food production, this potential shift in pest distribution poses significant risks for crop security and highlights the need for proactive research on how climate change might reshape pest populations across different altitudes.

Addressing these research gaps on the implications for Pest Management in Western is essential for enhancing pest management strategies in Western Kenya. The current knowledge of altitudinal pest distribution, while valuable, does not fully account for how altitude-specific factors such as fluctuating humidity, host plant diversity, and seasonal climate variations influence pest behavior and control methods. Locally focused studies are needed to assess these variables in Western Kenya’s highlands and mid-altitude zones, where variations in temperature and precipitation can affect pest prevalence. By identifying the specific ecological and physiological factors that allow pests to thrive in these zones, researchers can inform pest management practices that are tailored to the altitudinal characteristics of Western Kenya.

Given the unique challenges posed by altitude-driven pest distributions, research in Western Kenya should prioritize monitoring shifts in pest populations and examining the potential impact of climate change on pest dynamics across elevations. Enhanced understanding in these areas can help design adaptive management strategies that mitigate the risks of pest migration to higher altitudes, ensuring crop protection and food security in the region.

2.2.6 Analytical Approaches for Ecological Data

Altitude variation significantly influences both grass species diversity and the populations of stemborers (Busseola fusca and Chilo partellus) and fall armyworms (Spodoptera frugiperda). Studies suggest that pest prevalence is generally lower at higher altitudes, where cooler and wetter conditions support different grass species that may not effectively host these pests (Ngowi et al., 2020; Aloo et al., 2019). Using PCA, researchers can isolate environmental factors at play, revealing the relationships between altitude, grass diversity, and pest dynamics.

Additionally, NMDS can help visualize how pest populations vary across altitudinal zones, linking specific grass compositions to the prevalence of stemborers and fall armyworms. Recent research highlights a critical gap in understanding these altitude-specific interactions in Western Kenya, underscoring the need for targeted studies (Kibunja et al., 2021).

2.3 Influence of grass composition and characteristics on the populations of stemborers and fall armyworms in the grasslands surrounding maize farms at four different altitudes in Western Kenya.

2.3.1 Effect of Grasses on Stemborers and Fall Armyworm

The presence and composition of grasses in and around agricultural fields significantly affect stemborer and fall armyworm populations in Kenyan landscapes. While some grass species serve as trap plants, drawing these pests away from crops, others can inadvertently contribute to pest infestation by providing egg-laying sites for adult moths, especially early in the growing season when crops are still establishing. Fall armyworms (*Spodoptera frugiperda*) and stemborer species such as *Chilo partellus* rely on a range of grass hosts, including staple crops like maize and sorghum, which are primary hosts (Mishra et al., 2011). Thus, the composition of grass species near crop fields is a significant factor in determining pest pressure on crops.

In East African regions, maintaining grassy habitats near maize fields has shown potential for naturally controlling pest populations. For example, studies indicate that increased grass diversity around maize fields is associated with reduced stemborer infestation rates, possibly due to the support of natural pest enemies within these habitats (Ndemah et al., 2003a; Ong'amo et al., 2006). This ecological approach, leveraging natural biodiversity to reduce pest impact, has been shown to be an effective strategy; however, the specific effects of grasses on pest dynamics in the highland and mid-altitude zones of Western Kenya remain underexplored, presenting a significant research gap.

Research from the broader East African region suggests that a diverse assemblage of grasses near crop fields can act as a reservoir for natural predators and parasitoids of stemborers and fall armyworms. For instance, Matama-Kauma et al. (2008) demonstrated that border grasses could reduce crop infestation rates by diverting pests from crops. However, studies in Western Kenya have not thoroughly examined which local grass species best support beneficial insect populations or how specific grasses interact with common pests like stemborers and fall armyworms. Additionally, many of the documented interactions between grasses and pests are from lowland or central Kenyan regions, leaving a need for research into how these relationships may vary with Western Kenya's unique environmental conditions, such as higher rainfall and different temperature gradients.

Grass species with low economic value but high ecological value can potentially serve as "push" plants in a push-pull pest management strategy. This approach involves using border grasses to push pests away from crops while pulling them towards more attractive trap plants, reducing the likelihood of pest colonization within the main crops. Notably, studies in other East African regions have identified *Napier grass* (*Pennisetum purpureum*) as an effective trap plant for stemborers, reducing pest migration to maize fields (Khan et al., 2006). Despite this success, there is little research on the applicability of such strategies in Western Kenya, where climatic and geographical differences may influence the success of grass-based pest control methods.

Pest infestations, particularly stemborer attacks, are a leading cause of crop losses in Kenyan agriculture, with estimated maize yield losses ranging from 10% to 100% in severe cases (Mgoo et al., 2006). Such losses underscore the economic imperative to develop sustainable pest management practices. However, the majority of research on grasses as trap plants has focused on areas outside Western Kenya, overlooking the local grass species that may be more effective or more ecologically adapted to Western Kenya's highland and mid-altitude environments.

Further research is needed to identify native or adapted grasses that could serve as effective trap plants in Western Kenya's highland zones, where the pest pressure from stemborers and fall armyworms is compounded by the lack of natural predators in disrupted agricultural landscapes. Additionally, investigating how seasonal changes in grass abundance and composition affect pest pressure could help to optimize planting schedules for trap crops, enhancing pest control efforts. Addressing these research gaps could provide a more tailored, sustainable pest management framework, preserving crop yields and supporting food security in Western Kenya.

By expanding research efforts to cover Western Kenya's specific environmental context and grass species composition, we can better understand how local biodiversity can be harnessed for pest control, potentially reducing the reliance on chemical pesticides and enhancing ecosystem resilience.

2.3.2 Ecology and Control of Stemborers

Since 1900, *Busseola fusca* (1901) and *Chilo partel*lus (Kfir, 1990) have been significant insect pests affecting crop fields in East Africa (Guofa et al., 2001). These pests cause major destruction to cereal crops throughout their growth stages, leading to yield losses between 26.7% and 80.4%.

B. fusca females lay up to 800 eggs on the leaf sheaths of pre-tasseling plants (McVicar et al., 2012). Eggs hatch in about a week, and larvae migrate to the plant's whorl, where they feed on younger leaves (Calatayud et al., 2014). The larval stage can last up to 50 days, covering 7-8 instars under optimal conditions (Sisay et al., 2018). Adults emerge approximately 14 days after pupation, with males emerging before females (Scott et al., 2006). The average lifespan of *B. fusca* moths is about 10 days (McVicar et al., 2012).

(Figure 1).

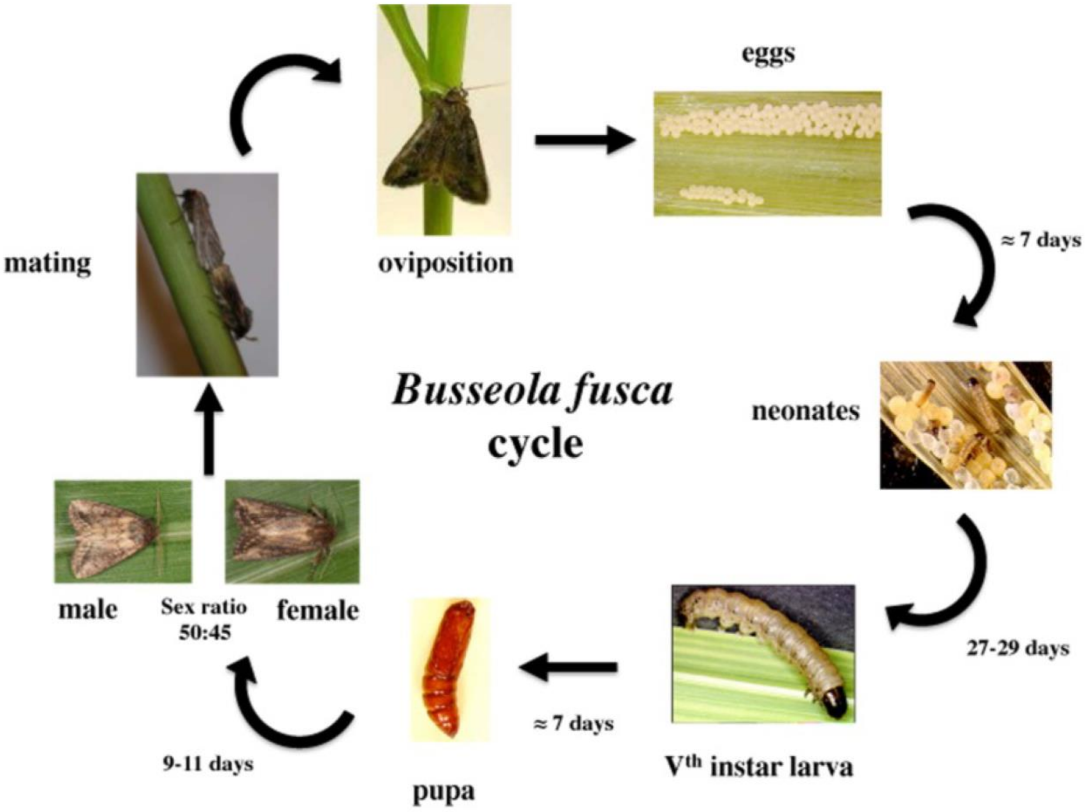

Figure 1: Life cycle of *Busseola fusca* (photo courtesy of Calatayud et al., 2007).

C. partellus lays eggs in batches of 10-80 on leaf surfaces. Larvae are yellowish-brown with purple-brown stripes and dark spots, and pupae are slender and light yellow-brown. Adults are small moths with distinct wing patterns (https://keys.lucidcentral.org). (Figure 2).

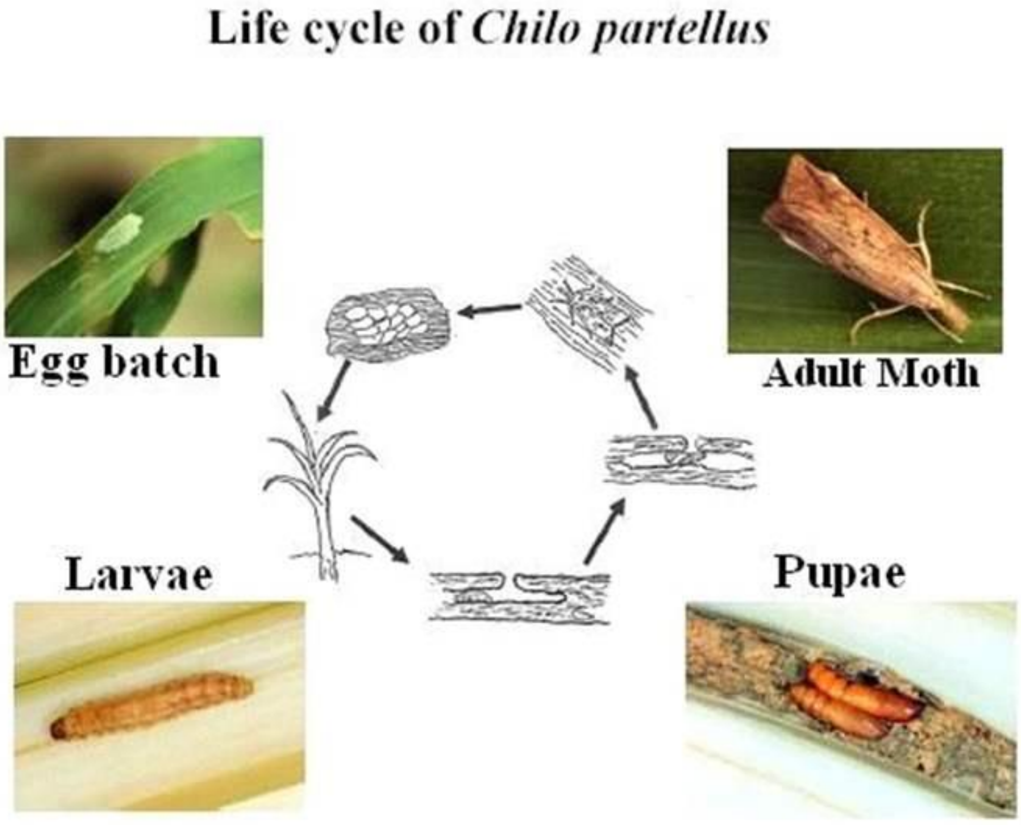

Figure 2: Life cycle of *Chilo partellus* (photo courtesy of http://harvestchoice.org).

2.3.3 Control of Stemborers

Biological control methods, like parasitoids and predators, have been employed but have not provided a permanent solution (Prasanth et al., 2010). Integrated Pest Management (IPM) is recommended for controlling maize stemborers and maximizing yield (Khan et al., 2015). Wild grasses near maize fields can support stemborer survival and colonization of cereal crops (Haile & Hofsvang, 2001). The push-pull approach involves using specific grasses to repel gravid moths, demonstrating effectiveness in managing stemborers and other pests (Midega et al., 2018). (plate 1).

Plate 1: stemborer feeding in the stem of maize (photo courtesy of https://extension.entm.)

2.3.5 Ecology and Control of fall armyworms

The fall armyworm (*Spodoptera frugiperda*) emerged in Africa in 2016 and has spread across the continent, causing significant damage to crops (Suby et al., 2020). FAW larvae feed on more than 350 plant species, including maize, and can result in yield losses up to 73% (Sokame et al., 2019). FAW also preys on stemborers, contributing to their decline (FAO and CABI, 2019). Understanding the interactions between FAW and stemborers is crucial for effective control (Id et al., 2019).

Plate 2: Spodoptera frugiperda on corn maize plant as a host (photo courtesy of G. Goergen et al., 2016).

FAW eggs hatch in 2-4 days, and larvae undergo six growth stages over 14-22 days before pupating (https://www.dpi.nsw.gov.au). The pupal stage lasts 8-30 days, depending on temperature, and adults can lay eggs within 4-5 days after mating. The eggs of FAW are laid on or under the surface of the leaves in clusters (Plate 3). The color of the eggs is pale yellow (On and The, 2020).

Plate 3: Fall armyworm egg mass (photo source, Queensland DAF).

The larvae of the FAW are light green to brown, having a dark head. The young larvae feed on leaves of host plants, leaving the ‘windows’ like cuticles on the leaf, which shows the presence of the larvae on the plants. (Plate 4) (Abang *et al*., 2021).

Plate 4: Small fall armyworm larvae on maize plant (photo source, Queensland DAF).

The large larvae have "Y" shape between the eyes. They are 3-4 cm long, which are darker with pale white stripes along the length of the body (Plate 5). They have dark spines, which have two dark spots on each body segment on the upper part, with 4 black spots in a square on the last abdominal segment.

Source: SABC, 2019, adapted from Matt Bertone, 2014

Plate 5: fall armyworm caterpillar (Large) - (photo source, Clemson University, USDA Cooperative Extension Slide Series, Bugwood.org).

The pupae of the fall armyworm are found in shiny brown soil between 1.3 and 1.7 cm long.

The moths of the adult FAW are 3-4cm. The male FAW moths are smaller than the females, but both sexes have a white hind wing with a dark- brown margin. The male FAW moths are more patterned and have distinct triangular white spots at the tip and near the Centre of each forewing (Lalruatsangi, 2021)).

Plate 6: Male fall armyworm moth (photo source, Lyle Buss, University of Florida, Bugwood.org)

The fall armyworm (FAW) completes its life cycle in approximately 23-27 days under suitable temperatures on host plants. Eggs typically hatch within 2-4 days after being laid. The FAW larvae undergo six growth stages over 14-22 days to reach maturity. Mature larvae then drop to the ground where they pupate, taking around 20-30 days in cooler areas and eight-9 days in warmer areas. Female moths can lay eggs within 4-5 days after mating. Unlike some insects, FAW does not enter diapause during the pupal stage. Populations of FAW are unlikely to establish in areas where temperatures drop below 9°C (https://www.dpi.nsw.gov.au)(7)

Plate 7: Female fall armyworm moth (photo source, https://ausveg.com)

2.3.6 Control of Fall Armyworm

Efforts to manage the fall armyworm (FAW) (Spodoptera frugiperda) have largely relied on synthetic insecticides due to the pest's rapid reproduction and ability to cause significant crop damage. However, this reliance poses multiple challenges, including the development of resistance among pest populations and potential environmental pollution. For instance, studies have shown that the overuse of certain insecticides can lead to resistant strains of FAW, making subsequent control efforts less effective and increasing the need for higher pesticide doses, which further exacerbates environmental contamination (Ahissou et al., 2021; Shetty et al., 2010).

Integrated Pest Management (IPM) offers a more holistic and sustainable approach to FAW control, emphasizing the use of a combination of methods rather than relying solely on chemical treatments. This strategy includes cultural practices, biological control, and monitoring to reduce pest populations effectively. According to Midega et al. (2012), successful IPM programs require comprehensive training for farmers to ensure that they implement techniques such as crop rotation, intercropping, and the use of pest-resistant plant varieties. Timing is also crucial; for example, monitoring pest populations and applying interventions at the right developmental stages can significantly improve management effectiveness.

Moreover, IPM encourages the use of natural enemies and biopesticides, which can help maintain ecological balance while reducing reliance on harmful chemicals. This multifaceted approach not only addresses the immediate threat of FAW but also contributes to long-term agricultural sustainability by promoting practices that enhance soil health and biodiversity.

2.3.7 Analytical Approaches for Ecological Data

Grass species composition and characteristics in Western Kenya's grasslands directly influence pest populations. Some grass species attract stemborers and fall armyworms, serving either as primary habitats or secondary hosts, which facilitate pest migration into maize fields (Midega et al., 2020; Ochieng et al., 2021). Employing PCA and NMDS in studies of grass composition can clarify which grass species are more or less favorable for these pests, providing essential insights for integrated pest management strategies.

Research indicates that certain grasses, like Pennisetum purpureum, can act as effective trap crops, reducing stemborer populations in adjacent maize fields (Muchugu et al., 2019). Identifying and mapping these relationships through rigorous analysis can inform pest management strategies that leverage the natural deterrent properties of specific grass species, enhancing maize crop resilience.

2.4 Effect of grass composition and characteristics on the populations of stemborers and fall armyworms within maize farms located at four varying altitudes in Western Kenya

The interaction between grass composition, characteristics, and pest populations, specifically stemborers and fall armyworms (Spodoptera frugiperda), is critical for developing effective pest management strategies in maize farming. In Western Kenya, varying altitudes create distinct ecological niches that affect both grass and pest dynamics. The fall armyworm, an invasive pest, adds another layer of complexity to these interactions. Studies suggest that this pest is highly adaptable, with a preference grass types that offer suitable feeding conditions (Van den Berg, 2019). Grasses with broad, tender leaves are particularly attractive to fall armyworms, increasing their populations and posing a significant risk to maize crops planted nearby (Midega et al., 2020). Despite the advances in understanding these dynamics, there is a noted scarcity of studies examining how specific grass types at various altitudes influence fall armyworm behavior, indicating a clear gap in the literature that needs to be addressed.

2.4.1 Role of Grass Species in Pest Dynamics on maize farms

Grasslands adjacent to maize fields can provide alternative habitats and feeding grounds for stemborers and fall armyworms. Research indicates that specific grass species influence pest behavior and the overall susceptibility of maize crops. For example, Midega et al. (2018) and Muchugu et al. (2019) found that Pennisetum purpureum (napier grass) can act as a trap crop for stemborers, effectively reducing their populations in maize. Conversely, other species such as Sorghum arundinaceum and Cymbopogon spp. may serve as secondary hosts, promoting pest migration into maize fields.

2.4.2 Influence of Altitude on Pest Populations

Altitude significantly impacts pest and grassland ecology in Western Kenya. Higher altitudes generally feature cooler and wetter conditions, which can suppress stemborer prevalence due to the distinct grass species that thrive there (Ngowi et al., 2018). Lower altitudes, characterized by warmer and drier climates, favor grass species that create suitable habitats for larger pest populations. However, research by Otieno et al. (2020) emphasizes a gap in understanding these altitude-specific pest-grass dynamics, highlighting the need for pest management strategies that consider the unique conditions of Western Kenya.

The fall armyworm's adaptability to various host plants complicates pest management strategies. Studies by Van den Berg (2019) and Midega et al. (2020) indicate that grasses with broad, tender leaves are particularly conducive to supporting fall armyworm populations. This relationship poses a significant risk to maize crops situated near these grasses. Despite recent advances, there is a scarcity of detailed studies investigating how specific grass types at different altitudes influence fall armyworm behavior, underscoring the need for targeted research.

Despite progress in understanding the interactions between grass composition and pest dynamics, substantial research gaps remain. Existing studies often generalize findings across broader ecological zones, neglecting the specific grass compositions of Western Kenya. For instance, species like Themeda triandra and Pennisetum spp. may interact uniquely with pests due to varying environmental conditions. Kebenei et al. (2018) and Muchugu et al. (2019) stress the importance of examining seasonal grass phenology to understand how pest pressures fluctuate throughout the year, an area that has not been adequately explored.

2.4.3 Implications for Pest Management Strategies

Addressing these research gaps is crucial for developing effective pest management strategies. Identifying grass species that deter stemborers and are less conducive to fall armyworm infestations, especially at varying altitudes, can help create natural barriers that limit pest migration to maize fields. Kebenei et al. (2018) advocate for integrating native grasses that are less attractive to pests into pest management frameworks, preserving grassland biodiversity while protecting maize crops from infestations. Understanding the intricate relationships between grass composition, pest populations, and altitude is vital for improving pest management practices in maize farming across Western Kenya. Further research focusing on these dynamics will provide valuable insights for developing sustainable agricultural practices that enhance crop resilience while maintaining ecosystem health.

2.4.4 Analytical Approaches for Ecological Data

Investigating the impact of grass composition on the populations of stemborers and fall armyworms within maize farms involves comprehensively understanding the interactions between grassland ecosystems and agricultural systems. PCA can help identify the principal components affecting these interactions, while NMDS can provide a nuanced visualization of how different grass species relate to pest populations in specific ecological contexts.

Existing literature emphasizes the need for detailed studies focusing on specific grass species found in Western Kenya, particularly regarding the unique ecological gradients presented by altitude (Kebenei et al., 2020; Njuguna et al., 2021). Applying these analytical methods can help clarify relationships between grass characteristics and pest dynamics, filling critical knowledge gaps that can inform effective pest management practices tailored to local conditions.

CHAPTER THREE

METHODS AND MATERIALS

3.1 Sites of study

The study was conducted across four altitudinal zones in Western Kenya Mt. Elgon (1600-1800 masl), Vihiga (1400-1600 masl), Homabay (1200-1400 masl), and Lambwe (1000-1200 masl) representing very high, high, medium, and low altitudes, respectively, where maize farms and adjacent grasslands were examined for grass composition and pest populations. In Vihiga, the farms were located at Nactical (00°04'59"N, 034°34'604"E), Chelamba (00°05'598"N, 034°35'628"E), Patrick (00°01'667"N, 034°33'980"E), and Jairus (00°00'399"N, 034°35'332"E); in Mt. Elgon, at Agnes (00°47'452"N, 034°29'119"E), Kapule (00°48'297"N, 034°29'286"E), Laban (00°48'846"N, 034°29'988"E), and Moses (00°48'745"N, 034°29'791"E); in Homabay, at Angeline (00°38'501"S, 034°30'980"E), Reuben (00°36'720"S, 034°29'695"E), Pamela (00°37'769"S, 034°29'642"E), and Domnicus (00°35'420"S, 034°25'953"E); and in Lambwe, at Oyoo (00°34'422"S, 034°19'203"E), Mary (00°33'698"S, 034°18'963"E), Otieno (00°00'163"S, 034°35'954"E), and Sanaa (00°33'551"S, 034°18'242"E). Each site was selected based on maize farming activity, with farmers maintaining at least two plots, facilitating a midpoint for sampling. Grass species and pest populations were sampled during the short rain season of 2019 and the long rain season of 2020 to capture seasonal variation in species diversity and abundance across altitudinal gradients.

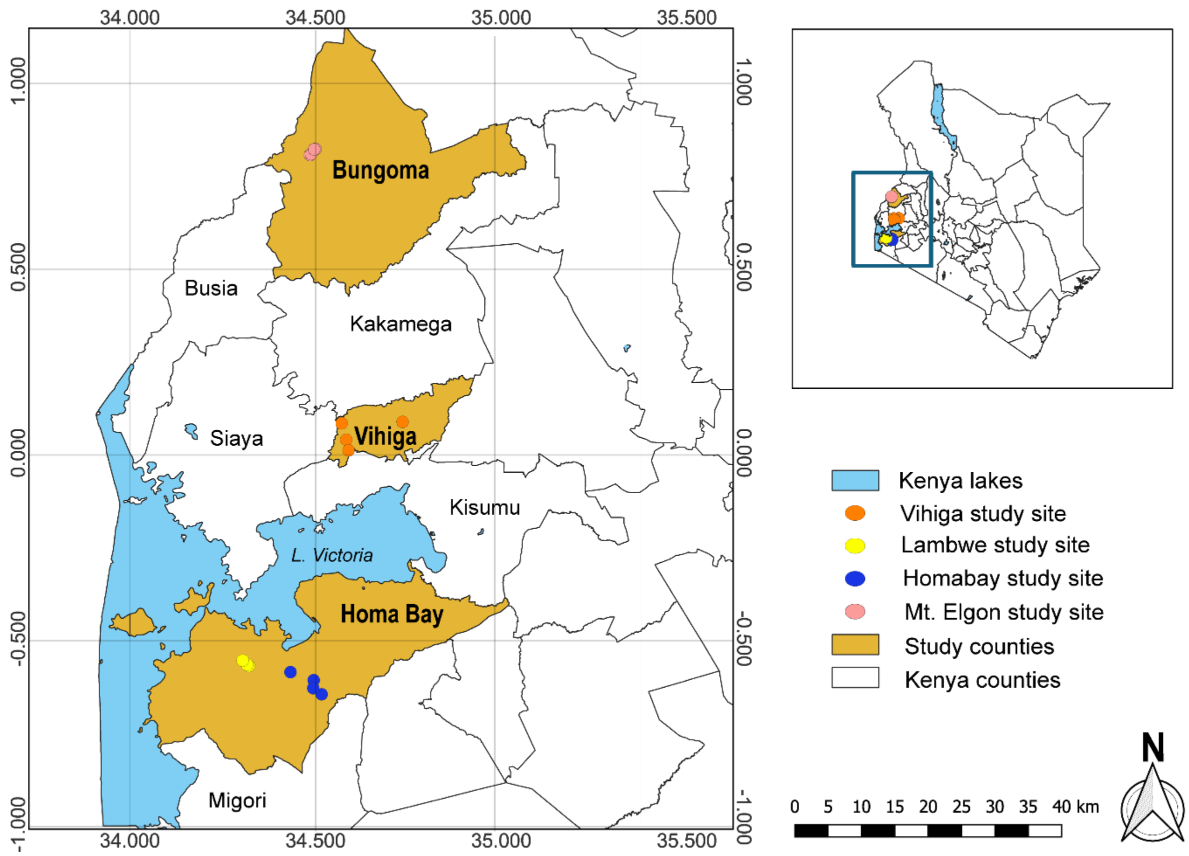

Figure 3: Study sites

3.2 Sampling design

The study employed a systematic purposive sampling design to capture data across four different elevations, selected based on varying altitudes. Farms were chosen based on their elevation, ensuring each elevation category was represented. To minimize spatial autocorrelation and ensure independent sampling, each farm was located at least 2 kilometers apart within each site. The GPS coordinates were recorded using Garmin e Trex handheld GPS.

3.3 Methodology for Data Collection

This study utilized a systematic sampling framework using quadrats and transects to document ecological and pest data within maize-associated grasslands across altitudes in Western Kenya. The design focused on evaluating grass species abundance, richness, cover, fresh weight, and pest populations by integrating updated field sampling and pest surveillance methodologies.

3.3.1 Transect and Quadrat Design

Transects allow comprehensive spatial coverage and have proven effective for vegetation and pest data collection in agricultural settings. Following a central sampling point between maize plots, transects extended in the four cardinal directions to account for environmental variability across the farm landscape. This approach aligns with best practices outlined in recent studies on sampling designs in complex landscapes (Almeida-Gomes et al., 2019; Zhao et al., 2020). Quadrats of 0.5 x 0.5 meters were systematically placed at 100-meter intervals along each transect (at 100 m, 200 m, 300 m, 400 m, and 500 m), ensuring a structured and repeatable sampling grid (Garba et al., 2020).

3.3.2 Grass Species Abundance and Richness

For grass species abundance, each quadrat was meticulously examined to document individual grass species, ensuring accurate counts and identification in alignment with standard biodiversity monitoring protocols (McNaughton et al., 2019). To assess species richness, all unique species within each quadrat were recorded, enabling effective monitoring of species diversity across altitudinal gradients (Paudel et al., 2019). This data provided insights into how grass diversity shifts in relation to elevation—a factor shown to be pivotal in influencing ecological dynamics in previous studies (Herman & Weaver, 2020). Point intercept method was employed as a precise and systematic approach to measure grass species composition, distribution, and biomass within quadrats across the study sites. This method involves positioning a grid or frame of 0.5 x 0.5 meters (or 0.25 m^2) over each sampling quadrat to delineate the area for study. The frame was divided into smaller, equal units, creating a structured sampling grid that facilitated consistent data collection across each quadrat. By placing this frame at designated intervals along pre-established transect lines, the study ensured thorough and uniform coverage across all altitude gradients, making it possible to analyze and compare vegetation characteristics across sites of differing elevations (Kent & Coker, 1992).

Once the quadrat frame was set, an intercept pin or thin rod was used to identify plant species by systematic sampling at multiple points within each quadrat. At each predetermined sampling point, the pin was vertically lowered until it made contact with the ground, recording each instance where it intercepted vegetation. These contact points, known as “intercepts,” provided data on the presence of grass species within each quadrat, with each contact counted as an individual intercept. This standardized pin-lowering method at each sampling point provided an unbiased means of recording species presence and facilitated easy replication across sites, minimizing observer error and ensuring consistency (Kent & Coker, 1992).

For each intercept, the grass species present was identified and recorded based on its physical characteristics, referencing comprehensive field guides or species identification manuals for accuracy (Mueller-Dombois & Ellenberg, 1974). This process enabled precise species composition documentation, where each recorded species' name, frequency of appearance, and relevant observational notes were meticulously noted in a field notebook. The grass species that were not identified in the field were uprooted, including the stolons and underground parts such as roots and rhizomes and collected. They were mounted on a paper as herbarium specimen according to Fish et al., (2015). Other species were not identified because they were only morph species, which could only be identified genetically or molecularly. This systematic approach allowed the study to assess the relative frequency of each species, as each contact between the pin and a grass species was recorded as an individual instance of species presence within that quadrat.

In addition to providing data on species composition, the method indirectly estimated biomass based on the frequency of intercepts per species; more intercepts indicated denser, more abundant vegetation, thereby serving as a proxy for biomass. For instance, a species with a high number of intercepts in a given quadrat suggested greater biomass relative to less frequently intercepted species. By tracking and recording, these intercept counts across quadrats at various altitudes, the study could analyze grassland structure, density, and biomass distribution in a way that was consistent and comparable across sites (Bonham, 2013).

In measuring grass species abundance, each intercept recorded per species within a quadrat served as an essential metric for estimating both relative abundance and vegetation density. Each time a pin intercepted a grass species, it was logged as an occurrence of that species, thus giving a direct measure of abundance based on contact frequency. The frequency of these intercepts was critical in assessing species distribution and density, as a higher intercept count for a given species suggested denser growth within the quadrat, effectively serving as a proxy for biomass (Elzinga et al., 2001). This approach allows for a non-destructive way of estimating biomass by interpreting intercept frequency as an indicator of vegetation density and, indirectly, plant productivity.

Each species intercept count was compiled across quadrats, enabling a quantitative assessment of both frequency and abundance. Specifically, species frequency was recorded as the number of quadrats in which each species appeared, providing an indication of how widespread each species was across the sampling sites. In contrast, relative abundance was calculated as the proportion of intercepts per species within each quadrat, giving insight into the dominance or prevalence of each species relative to others within the quadrat and allowing comparisons across sampling areas with different altitude gradients. This comparative analysis helped reveal how altitude and site conditions influenced vegetation structure, with species abundance patterns highlighting areas of dense or sparse grass cover.

Additionally, species richness was determined by counting the total number of unique grass species within each quadrat, providing insights into biodiversity and species composition at each study site. Species richness was recorded alongside abundance to yield a more comprehensive view of the ecosystem structure, showing not only which species were abundant but also the diversity present at each site. Higher species richness in a quadrat suggested a more diverse grassland composition, while lower richness indicated fewer species, potentially pointing to dominant or specialized vegetation suited to particular environmental conditions.

By integrating these measures species frequency, relative abundance, and richness the study captured a multi-dimensional view of grass species composition and diversity at different altitudes. These metrics were essential in identifying patterns of grassland composition and density, which could then be analyzed to infer ecological factors driving species distribution. The systematic data recording and compilation process across quadrats ensured accuracy and consistency in the findings, allowing the study to present robust conclusions on how grassland vegetation varies across elevational gradients, with implications for understanding habitat structure, biodiversity, and ecological interactions in different environmental contexts (Elzinga et al., 2001; Kent & Coker, 1992).

To estimate biomass, the frequency of intercepts per species was used; intercepts that are more frequent indicated denser vegetation, thus suggesting higher biomass. By applying this proxy, the study gauged vegetation density efficiently across each sampling site (Brown, 1985). Field data, including species name, intercept counts, and quadrat totals, were recorded on data sheets for accuracy. These sheets allowed for later aggregation and analysis, providing a comprehensive view of grass species composition and abundance across study sites, aiding in understanding the link between grassland characteristics and pest populations adjacent to maize farms (Sutherland, 2006). Following consistent ecological survey practices, the point-intercept method provided the study with a robust framework to systematically analyze grass species composition, distribution, and biomass across varying elevations (Bonham, 2013).

3.3.3 Percentage Cover

The study estimated percentage cover by visually assessing the proportion of quadrat space occupied by each grass species. This method, widely adopted for its ease and reliability, is well-suited for grassland cover estimation, as demonstrated in vegetation studies that emphasize cover as an indicator of ecosystem structure (Alvarez & Cushman, 2019; Gornish et al., 2019). By implementing this method, the study provided comparable vegetative cover data across sites, aiding in the assessment of ground cover variability at different altitudes. To determine grass percentage cover, a standardized 10 x 10 cm grid was used within each 0.25 m^2 quadrat to provide a consistent measurement basis. This grid size represented 4% of the total quadrat area, allowing researchers to systematically assess the proportion of the quadrat covered by grass. For example, if the grass covered only one 100-cm^2 grid square, the percentage cover was calculated at 4%. However, if grass occupied the entire 0.25 m^2 quadrat (25 grid squares), the percentage cover was recorded as 100% (Kent & Coker, 1992). A direct overhead view was used to enhance visibility and ensure accuracy in estimating each species’ percentage cover, minimizing observer bias.

To aid in future analysis and revisits, all quadrats were assigned precise GPS coordinates. This enabled consistent tracking of changes over time and facilitated precise re-sampling if required (Elzinga et al., 2001). In addition to the visual estimation of cover, all grass within each quadrat was clipped at ground level, sorted to exclude any non-grass species (forbs), and weighed in the field using a portable balance to measure fresh weight. This collection and weighing of all grass biomass offered a practical approximation of productivity per sampling area (Mueller-Dombois & Ellenberg, 1974).

To determine the dry weight and obtain a reliable measure of biomass, a 50 g subsample was taken from the clipped grass in each quadrat. This sample was oven-dried at 85°C for 48 hours to eliminate moisture content and provide an accurate dry weight measurement, which was essential for calculating biomass unaffected by water content. The dry weight per quadrat was then calculated with the formula:

$$Total\ weight = \frac{Sub\ sample\ dry\ weight}{Sub\ sample\ fresh\ weight} \times Total\ fresh\ weight$$

The estimated biomass per quadrat was converted to biomass per square meter by multiplying by 4, accounting for the initial quadrat size of 0.25 m². This conversion enabled direct comparison across sites of differing environmental conditions and provided a standardized measurement per unit area (Kent & Coker, 1992).

To further analyze biomass variation across elevations, the fresh weight data was subjected to a Tukey's Honest Significant Difference (HSD) post hoc test. This statistical test was applied following ANOVA to compare mean biomass values between sites of different elevation categories (e.g., low, medium, high). Tukey's HSD test was selected due to its ability to handle multiple comparisons between groups while controlling for Type I error, allowing for accurate identification of significant differences in biomass between elevation levels (Yandell, 1993).

3.3.4 Fresh Weight Measurements

Fresh weight measurements were critical for biomass analysis. Grass samples were collected and weighed immediately to ensure moisture retention and measurement accuracy, a technique that is central to biomass studies (Ma & Herzon, 2020). This approach aligns with the need for accurate field-based biomass measurements, particularly in evaluating resource availability and primary productivity in agricultural landscapes (Muchiri & Ngowi, 2020). The weight of the fresh weight was weighed using portable balance and the weight was recorded in notebooks in grams.

3.3.6 GPS Coordinates for Spatial Accuracy

GPS devices were used to record each quadrat's coordinates, ensuring spatial accuracy in ecological studies. Incorporating GPS technology enables the detailed mapping of ecological and pest data in relation to environmental gradients, a practice supported in recent literature (Cheruiyot et al., 2019). This georeferencing method was essential for spatially consistent data collection across altitudinal zones in this study.

3.3.7 Standardized Data Sheets and Cross-checks

Pre-prepared data sheets facilitated systematic data collection for species abundance, richness, percentage cover, fresh weight, and pest incidence. Data recording followed crosschecking practices to ensure reliability, in line with field ecology protocols that prioritize data integrity (O’Connell et al., 2019). This standardized method helped minimize errors, ensuring a comprehensive and accurate dataset for assessing altitude-related influences on pest-host dynamics.

This structured sampling approach, reinforced by recent ecological methodologies, provided a robust dataset on grass and pest populations across various altitudes. Through systematic and spatially accurate data collection, the study captured critical ecological interactions in maize ecosystems, highlighting the role of altitude and grassland composition in pest dynamics.

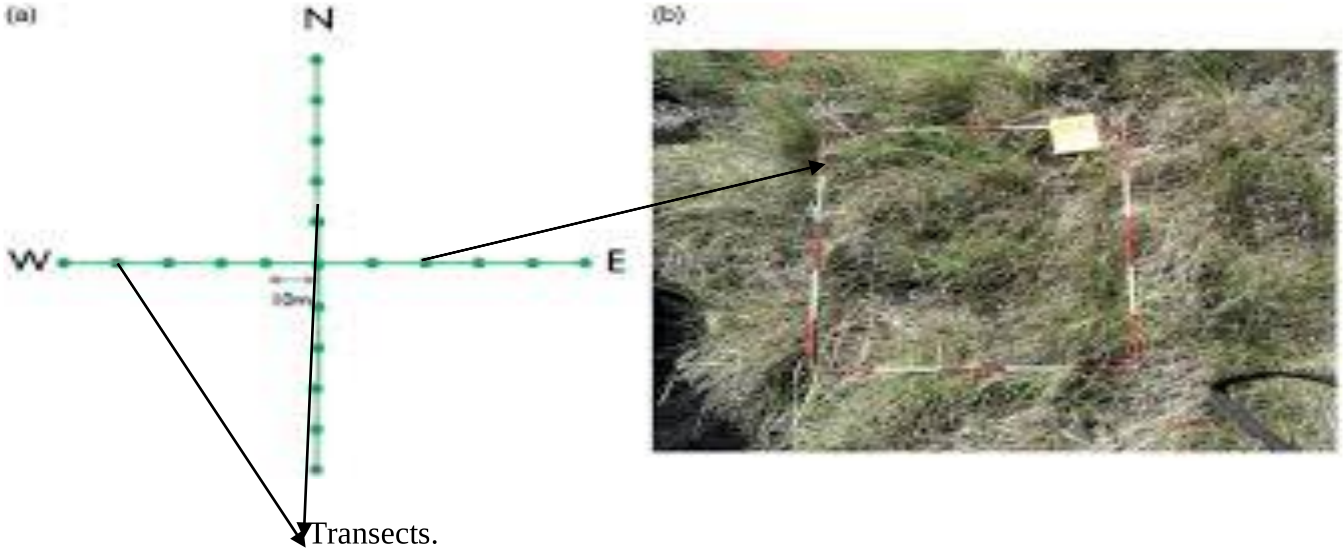

Plate 8: Transects with quadrates used during sampling.

3.4 Determination of grass species diversity

In each quadrat, grass species were identified, counted, and recorded to facilitate later calculations of species richness and species diversity, foundational measures for assessing community structure and ecosystem health (Kent & Coker, 1992). Each quadrat, measuring 0.5 x 0.5 meters, was positioned at 100-meter intervals along each transect, ensuring representative sampling across the study area. After recording species abundance, all grass within each quadrat was clipped at ground level to obtain fresh biomass. The clipped grass was then weighed in the field using a portable balance to record fresh weight as a proxy for productivity (Mueller-Dombois & Ellenberg, 1974). To standardize measurements, the grass samples were then placed into brown paper bags and transported to a controlled drying facility, where they were oven-dried at 85°C for 48 hours. This drying process eliminated water content, ensuring an accurate dry weight measure that reflects actual biomass.

To quantify grass diversity, the Shannon-Wiener diversity index (H) was calculated. This index is widely used in ecological studies to estimate species diversity by combining species richness (S) and species evenness (relative abundance). The Shannon-Wiener index formula is as follows:

$$H = \sum_{i=1}^{S} [P_i \times \mathrm{Ln}(P_i)]$$

Where, H is Shannon-Wiener diversity index, S is the Species richness, P_i is the biomass percentage of each species in community biomass, Ln is the natural logarithm, N, the total percentage cover of the grass species, the grass species, pi, the proportion of the N made up of the ith species. In this context, the biomass percentage of each species (P_i) is calculated as its proportion of the total grass biomass in the quadrat, ensuring that both abundance and biomass are incorporated into the diversity calculation. Since the Shannon-Wiener index typically produces a negative value, 1 to yield a positive figure, which is more interpretable and aligns with common reporting practices in biodiversity studies (Shannon & Weaver, 1949), multiplied the result.

This method allowed for a detailed analysis of species diversity and abundance patterns, providing insights into community composition and how grassland ecosystems vary across environmental gradients such as elevation.

3.5 Determination of Grass species distribution

Determined the distribution and variation of grass species composition across different quadrats and elevations, data analysis was conducted to examine patterns influenced by environmental gradients, such as elevation. After identifying the grass species present at each sampling point, Non-Metric Multidimensional Scaling (NMDS) was applied to visualize species distribution across four elevation levels. NMDS is a widely used ordination technique for ecological data, allowing researchers to assess similarities and differences in species composition by creating a simplified, interpretable visual representation (Legendre & Legendre, 2012). This method operates by maximizing rank-order correlation between calculated distance measures and spatial distances in the ordination plot, adjusting points iteratively to minimize stress, or the discrepancy between actual and plot-based distances.

Data from each quadrat, including abundance measures for different grass species, was organized into a matrix format, where rows corresponded to sampling points and columns to individual grass species, with cell values reflecting species abundance. A distance matrix was then constructed to quantify dissimilarities between sampling points based on their species composition. Through iterative adjustments, NMDS optimized the spatial arrangement of points to achieve a low-stress value, which indicates a high-quality fit for the data. Visualization of the NMDS results was achieved with ordination plots in which each point represented a unique sampling location, and color coding differentiated between the four elevation levels, thereby enabling easy recognition of altitude-related composition patterns (Clarke, 1993).

The NMDS analysis revealed that species composition varied markedly across the four elevation levels, with proximity between points indicating greater similarity in grass composition between sampling locations. By comparing species composition across quadrats and elevations, the analysis provided a clear visualization of ecological variations with altitude, supporting a deeper understanding of the distribution and dynamics of grassland ecosystems in Homabay County.

To further investigate the variation in grass species composition across sites, a Permutation Multivariate Analysis of Variance (PERMANOVA) was conducted, categorizing sites into four distinct elevation levels: Mt. Elgon (Very High), Vihiga (High), Homabay (Medium), and

Lambwe (Low). Each grass species within the quadrats was recorded, along with measurements of total grass cover and average grass height, assessed by sward height with a ruler (Fish et al., 2015). PERMANOVA was chosen because it offers a robust statistical framework for testing significant differences in composition across elevation categories without requiring multivariate normality or homogeneity of variances (Anderson, 2001).

The PERMANOVA results were visualized through ordination plots, which highlighted ecological differences in grass composition across the sampled elevations. By using a distance matrix directly, PERMANOVA effectively emphasized significant variations in species composition across different altitudes, underscoring the impacts of elevation on grassland biodiversity. This dual approach using NMDS and PERMANOVA provided valuable insights into the effects of elevation on grassland ecosystems, offering a comprehensive view of species composition variability and ecological dynamics across different altitudinal zones.

3.7 Determination of Stemborer and Fall armyworm Population in maize farms and on grasses sorrounding maize farms

The presence of stemborers (Busseola fusca, Chilo partellus) and fall armyworms (Spodoptera frugiperda) was determined through structured pest surveillance. Recent protocols for pest monitoring emphasize examining each quadrat for larvae, eggs, and feeding damage, allowing for reliable pest density estimation (Harrison et al., 2020; Tambo et al., 2020). Pest samples were collected in containers for identification and tracking to ensure precision in species-specific pest assessments.

The sampling procedure for assessing stemborer and fall armyworm populations in maize farms was carefully designed to obtain accurate data on pest presence while minimizing edge effects, which can skew results. In each maize field, two rows of maize plants were left un-sampled along each edge of the field to avoid these edge effects, as they often lead to increased pest densities due to changes in environmental conditions such as light, wind, and moisture levels at field borders (Southwood & Henderson, 2000). The edge rows can serve as a buffer zone, ensuring that pest density measurements had better represent interior field conditions, which are more stable and less influenced by external factors.

Within the third row of each line, sampling began on the third plant after leaving the first two plants un-sampled. This selective sampling approach is based on research suggesting that plant density, pest movement, and environmental conditions can vary near the edges of each row. By beginning on the third plant, we further reduced any residual edge effects within each line, capturing data that more accurately reflect central plant conditions, which can provide a clearer understanding of pest presence and population density across the field rather than just along edges (Foster & Ruesink, 1984).

After selecting the initial sampling plant, every sixth plant was sampled, with five plants left in between. This systematic skipping pattern not only conserved time and resources but also allowed for representative coverage across each row without over-representing localized pest density hotspots, which may not be representative of the whole field. The larvae of fall armyworms and stemborers were carefully collected with forceps to avoid damaging them, and each specimen was preserved in 70% alcohol in Eppendorf containers, maintaining specimen integrity for accurate identification and counting in the laboratory.

This method was designed to balance accuracy and efficiency while minimizing edge effects that could influence pest distribution data. The approach aligns with best practices in pest sampling methodology, which emphasize reducing edge bias to obtain more uniform and representative samples from within the crop field (Southwood & Henderson, 2000; Pedigo & Rice, 2006).

3.8 Determination of effect of grass diversity and its characteristics on the population of stemborers and fall armyworm on grassland surrounding maize farms

To assess the impact of grass diversity and characteristics on the populations of stemborers and fall armyworms in grasslands surrounding maize farms, a combination of Principal Component Analysis (PCA) and Non-Metric Multidimensional Scaling (NMDS) was employed. This approach allowed for both dimensionality reduction and visualization of complex ecological relationships within the dataset. Specifically, PCA was used to condense variables such as species abundance, percentage cover, and average grass height into key components that captured the most variation in grassland characteristics, facilitating a more straightforward interpretation of the data (Legendre & Legendre, 2012).

Following PCA, NMDS ordination was conducted to analyze and illustrate similarities and differences in grass species composition across study sites. Unlike PCA, which is linear, NMDS is a non-linear ordination method that uses rank-order distances to accurately represent the ecological relationships between sites based on grass species composition and diversity, even in the presence of non-linear environmental gradients (Clarke, 1993). Pest population data were then overlaid on the NMDS ordination plots to explore associations between gradients of grass diversity and pest densities across the sites. This overlay allowed for visual assessment of pest population variations along the gradients of grass diversity, revealing how different grassland attributes, such as species richness and cover, correlated with the presence of stemborers and fall armyworms.

Through integrating PCA and NMDS findings, the study identified patterns and associations between grassland diversity characteristics and pest populations. This combined analytical approach offered robust insights into how variations in grass species composition and environmental factors may influence pest prevalence, which is crucial for developing pest management strategies in maize-adjacent grasslands (Legendre & Gallagher, 2001; McCune & Grace, 2002).

For studying the Impact of Altitude Variation and Grassland Composition on Population of Stemborer and Fall Armyworm on Maize Farms and Surrounding Grasslands over 2019 and 2020, a robust dataset of environmental variables was crucial. Key environmental parameters were selected, including temperature, rainfall, humidity, and solar radiation, all known to influence pest populations and grassland composition. Data acquisition relied on NASA's Earth Observing System Data and Information System (EOSDIS), offering extensive satellite-based datasets capable of meeting the spatial and temporal needs of the study (Jensen, 2016).

3.9.1 Selection and Frequency of Environmental Variables

To account for seasonal variability and other short-term environmental changes, temperature and humidity were sampled monthly to track both seasonal and immediate effects on pest populations. Monthly intervals were chosen based on the influence these factors can exert on pest life cycles, particularly during growing and pest migration seasons. Rainfall data, crucial for understanding moisture patterns impacting both grass and maize growth, were also collected monthly. This frequency allowed the study to capture both long-term rainfall trends and specific monthly fluctuations influencing pest activity and host plant conditions.

Solar radiation data were captured quarterly to observe broader seasonal patterns, as radiation levels impact plant growth cycles and indirectly affect pest habitats and feeding rates. Collecting radiation data quarterly provided a balance between necessary temporal resolution and the overall influence of solar exposure on vegetation throughout the study period. The study area's spatial extent and the dynamics of grassland composition, influenced by altitude, were carefully considered in setting up these sampling frequencies to ensure that environmental data aligned well with the variation in pest populations and vegetation patterns across the elevation gradients.

3.9.2 Preprocessing and Data Validation

To ensure high data accuracy, all remote sensing data underwent thorough preprocessing. This included atmospheric correction to adjust for changes due to moisture and particulates, sensor calibration to address inconsistencies across data collection periods, and geometric correction for spatial accuracy. The study leveraged grid cells based on the spatial resolution of the datasets, which were designed to align with quadrate data collected in field studies for a cohesive analysis across environmental and biological variables.

Data validation involved comparing remotely sensed data with independent ground-based datasets when available. Such comparisons provided quality assurance, ensuring that each environmental parameter aligned with on-the-ground conditions and offered realistic insights into the study area. Statistical analyses were then conducted to identify patterns and correlations between environmental parameters and pest population dynamics, allowing adjustments to models and interpretations where necessary to increase accuracy.

This comprehensive approach allowed the study to generate meaningful insights into the effects of altitude and grassland composition on pest populations, providing reliable data over the two-year period from 2019 to 2020. With monthly and quarterly data points, the temporal resolution effectively captured seasonal trends and localized environmental fluctuations impacting the pest populations in maize fields and surrounding grasslands.

3.9 Statistical Analysis

The analysis of ecological data in this study incorporated a combination of **descriptive, inferential, and multivariate statistical methods** to examine the relationships between grass species composition, environmental variables, and pest populations. All analyses were conducted using **R version 4.0.4** (R Core Team, 2021), a statistical programming language known for its wide array of ecological and biodiversity-focused packages.

3.9.1 Assessing Grass Species Richness and Abundance

Grass species richness was evaluated using the **BiodiversityR** package (Kindt & Coe, 2005). Species richness refers to the number of unique species within each sampling area, while species abundance measures the population size or frequency of each species. The BiodiversityR package ranked species by abundance, categorizing them into the most abundant (majority) and less abundant (minority) groups. This approach provided an overview of species diversity and allowed comparison across different elevations.

3.9.2 Distribution Analysis Using Non-Metric Multidimensional Scaling (NMDS)

Non-Metric Multidimensional Scaling (NMDS) was applied to visualize and explore differences in grass species composition across four elevation gradients. NMDS is a non-linear ordination method that emphasizes rank-based distance relationships rather than absolute values, making it ideal for ecological datasets that are often non-normal and contain complex interactions (Minchin, 1987). The NMDS ordination plots were constructed to visually represent grass species distributions by arranging sampling points based on species similarity, with points closer in space indicating similar species compositions.

3.9.3 Analyzing Variance with PERMANOVA

To assess variation in species composition between different sites, Permutation Multivariate Analysis of Variance (PERMANOVA) was conducted. PERMANOVA is a non-parametric multivariate test that evaluates whether centroids (mean positions) of groups differ, making it ideal for analyzing community data where traditional ANOVA assumptions do not hold

(Anderson, 2001). PERMANOVA examined the statistical significance of differences in species composition across four elevation levels, providing insights into how site elevation influences grass community structure and associated pest populations.

3.9.4 Examining Relationships with Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was utilized to reduce the dimensionality of the data and identify primary gradients or axes that explained the most variation among grass species and environmental variables. PCA biplots illustrated the alignment of certain grass species and environmental factors with these axes, revealing their influence on stemborer and fall armyworm populations. For example, the influence of variables like species richness, biomass, and percentage cover on pest abundance was highlighted by their position relative to the principal components in the ordination space, demonstrating how grassland composition varies with altitude (Legendre & Legendre, 2012).

3.9.5 Spearman's Correlation Analysis

To further analyze relationships between grass composition and pest abundance, **Spearman's correlation analysis** was performed. This non-parametric test assesses the strength and direction of associations between two variables without assuming a linear relationship. The correlation test quantified how specific grass characteristics (e.g., species richness, percentage cover) related to the population densities of fall armyworms and stemborers, providing insights into how grass diversity impacts pest populations (Corder & Foreman, 2014).

3.9.6 Comparative and Post Hoc Analyses with Tukey's HSD and t-Tests

3.9.6.1 Tukey's HSD Post Hoc Test

Differences in grass percentage cover and fresh weight among each elevation category were examined using Tukey's Honestly Significant Difference (HSD) test. Tukey's HSD, a post hoc analysis following ANOVA, identifies specific pairs of groups that differ significantly, enhancing understanding of how grass cover and biomass vary across elevation gradients.

3.9.6.2 t-Test

To compare the abundance of stemborers and fall armyworms on maize farms with that in surrounding grasslands, an independent samples t-test was conducted. By averaging pest abundance for each elevation category and treating each farm as a replicate, this test assessed whether maize fields or adjacent grasslands experienced higher pest pressures.

3.9.7 Modeling Pest Abundance with Regression Analyses

3.9.7.1 Linear Regression

The study applied linear regression to explore relationships between altitude, grass species diversity, and biomass. Linear regression models examined how elevation and diversity metrics influenced biomass production, providing insights into factors that may affect pest habitat suitability.

3.9.7.2 Generalized Linear Model (GLM) with Negative Binomial Distribution

To model stemborer and fall armyworm abundance on grasses, a GLM with a negative binomial distribution was used. This model accounted for overdispersion in count data, common in ecological studies with non-uniform distributions (Zuur et al., 2009). Grass characteristics, including percentage cover, dry mass, and species richness, were treated as predictor variables, allowing an evaluation of how these factors influence pest populations across different sites.

By integrating NMDS, PCA, and PERMANOVA for ordination and variation analysis, alongside Spearman’s correlation, Tukey’s HSD, and regression models, this study offered a robust framework for understanding how environmental factors and grassland diversity impact pest populations in maize farms and surrounding grasslands (Jensen, 2016). Each method contributed unique insights, from distribution patterns to correlation and causation, elucidating the complex ecological interactions at play.

CHAPTER FOUR

RESULTS

4.1 Grass Composition per Sites(altitudes)

The analysis of grass species composition across the four study sites (Lambwe, Homabay, Mt. Elgon, and Vihiga) during 2019 and 2020 revealed distinct seasonal patterns. In Lambwe, species richness increased from 1.52 in 2019 to 1.70 in 2020, with *Cynodon dactylon* showing a marked rise in dominance moving from second rank in 2019 (8,162; 17.1%) to the most abundant species in 2020 (17,637; 34.7%). In 2020, *Cyprus immesnsis* also emerged prominently as the second dominant species. In Homabay, species richness showed a slight increase from 1.65 to 1.78. *Elusine indica* was prominent in 2019 (9.7% of total composition), while *Echinochloa pyramidalis* became more abundant in 2020 (2.6%), indicating shifts in species prevalence. Higher altitude sites, such as Mt. Elgon, experienced an increase in species richness from 1.79 in 2019 to 2.02 in 2020, with a change in dominant species *Spp 44* in 2019 (2.3%) was replaced by *Spp 33* in 2020 (16.7%). Similarly, in Vihiga, species richness rose from 1.95 to 2.19, with *Cymbon nardus* becoming significantly more abundant in 2020 (15.7%), replacing *Pilgrimis spp*, which had a lower abundance in 2019 (0.4%). These results suggest clear seasonal dynamics and altitudinal variations influencing species composition and dominance. Table 1 below expresses in a clear and concise manner the key findings on species richness and abundance at each site over the two years. These results indicate that the grass species with higher abundance and proportion rankings contribute significantly to the overall species richness at each site (Table 1 below).

Table 1: Mean Species Richness, Abundance, and Proportion of Dominant Grass Species at Four Sites during 2019 and 2020

Site	Year	Mean species richness	Grass species	Rank	Abundance	Proportion
Lambwe	2019	1.52	*Cynadon dactylon*	2	8162	17.1
			Eustachys paspaloides	6	706	1.5
			Setaria incrasata	11	364	0.8
	2020	1.70	*Cynadon dactylon*	1	17,637	34.7
			Cyprus immesnsis	2	9098	17.9
Homabay	2019	1.65	*Elusine indica*	3	4619	9.7
			Chloris roxburghiana	5	866	1.8
	2020	1.78	*Echinochloa pyramidalis*	5	1326	2.6
Mt. Elgon	2019	1.79	Spp 44	4	1107	2.3
	2020	2.02	Spp 33	3	8476	16.7
Vihiga	2019	1.95	Pilgrimis spp	14	171	0.4
	2020	2.19	*Cymbon nardu*s	4	7951	15.7

4.1.1 Grass species richness in 2019 and 2020

Fifty-five (55) grass species were identified in 2020; during the long rain season and 32 grass species in 2019 during the short rain season. The grass species ranked accounted up to a proportion of 1% of the total abundance of all species for the four sites, Mt. Elgon, Vihiga, Homabay and Lambwe. In 2019, the grass species with highest abudance were *Cynadon dactylon* (17637), *Cyperus immensis* (9098) and Spp 33 (8476) followed by other grass species as shown in Table 2. (Appendix 12)

In 2020, the grass species with the highest abundance were *Cyperus immensis* (28030), *Cynadon dactylon* (8162) and *Elusine indica* (4619) followed by other grass species. (Appendix 13)

4.1.2 Mean Grass Species richness

In 2019, there was a notable difference in grass species richness between Lambwe and Vihiga, but no significant difference that was observed in grass species richness among Lambwe, Homabay, and Mt. Elgon. In the 2020 rainy season, Vihiga exhibited significantly higher grass species richness compared to Lambwe and Homabay. However, there was no significant difference in grass species richness among Lambwe, Homabay, and Mt. Elgon during the 2020 rainy season. (Table 2 below).

Table 2: Mean Grass Species Richness in Four Study Sites (Lambwe, Homa Bay, Mt. Elgon, and Vihiga) for 2019 and 2020

Values with the same letter in the column are not significantly different ($p > 0.05$).

Sites	**Mean Species Richness (2019)**	**Mean Species Richness (2020)**	**LSD (2019)**	**LSD (2020)**
Lambwe	1.52 ± 0.117 [a]	1.70 ± 0.1066 [a]	0.30	0.28
Homa Bay	1.65 ± 0.1098 [ab]	1.78 ± 0.1026 [a]	0.30	0.28
Mt. Elgon	1.79 ± 0.1021 [ab]	2.02 ± 0.0909 [ab]	0.30	0.28
Vihiga	1.95 ± 0.0941 [b]	2.19 ± 0.0836 [b]	0.30	0.28

The **LSD** (Least Significant Difference) value represents the smallest difference between means that is statistically significant at the specified confidence level. Values with the same letter (a, b) are not significantly different from each other within the same year, indicating that differences in species richness were not statistically significant between those sites.

4.1.3 Grass species distribution

The analysis of grass species distribution using Non-Metric Multidimensional Scaling (NMDS) and Permutation Multivariate Analysis of Variance (PERMANOVA) revealed significant patterns in grass composition across different elevation categories during the 2019 and 2020 cropping seasons. The NMDS technique visualized ecological data in a reduced-dimensional space, highlighting similarities or differences in species composition across study sites based on altitude. The results showed that the distribution of grass species clusters varied significantly with elevation, statistically confirmed by the PERMANOVA results ($P < 0.005$). This indicates that elevation has a notable impact on the grass species found in each location.

In 2019, the PERMANOVA analysis identified significant differences in grass composition between high and very high elevations, and between very high and medium elevations ($P < 0.05$). This means that grass species composition in high-altitude regions, such as Mt. Elgon, was significantly distinct from that in other elevation categories, particularly medium-altitude areas.

For instance, the species richness and dominant grass species composition in very high elevations differed noticeably from those in medium elevations, suggesting that the environmental conditions such as temperature, humidity, and rainfall patterns at higher altitudes have a marked influence on the types of grass species that thrive there.

The 2020 data further emphasized the impact of altitude on grass composition, showing significant differences not only between high and very high elevations but also between high and medium, high and low, and very high and low elevations ($P < 0.05$). This suggests a clearer stratification of grass species as the altitude changes. For example, low-altitude sites like Lambwe had a composition distinctly different from high-altitude regions. This indicates that grass species adapted to lower temperatures and unique moisture conditions at high elevations do not thrive or exist in lower altitudes, and vice versa. (Table 3 below). The very high, High, Medium and lows means the Sites; Mt. Elgon, Vihiga, Homabay and Lambwe

Table 3: Results of permutation multivariate analysis of variance, (PERMANOVA) for global comparison among elevation categories, and pairwise comparisons for data from four study sites: Lambwe, Homabay, Mt Elon and Vihiga

	R^2	*P*
2019		
Global		
Very high-High-Medium-Low	0.342	0.005
Pairwise		
Very high-High	0.257	0.033
Very high-Medium	0.272	0.020
Very high-Low	0.322	0.149
High-Medium	0.229	0.088
High-Low	0.336	0.060
Medium-Low	0.152	0.386
2020		
Global		
Very high-High-Medium-Low	0.454	0.002
Pairwise		
Very high-High	0.355	0.033
Very high-Medium	0.266	0.112
Very high-Low	0.426	0.029
High-Medium	0.291	0.028
High-Low	0.501	0.024
Medium-Low	0.237	0.174

4.1.4 Non-Metric Multidimensional Scaling (NMDS) Analysis of Grass Species Composition at Lambwe, Homabay, Vihiga and Mt. Elgon

The NMDS analysis provided insights into the seasonal composition, distribution, and characteristics of grasses in grasslands adjacent to maize farms, with clear associations between grass species and elevation categories. The NMDS plots (Figures 4 and 5) depicted distinct clustering patterns based on elevation, emphasizing significant variation in species composition. The analysis yielded a stress value of 0.10, indicating a good fit and reliability of the NMDS solution.

Grass species composition at low elevations(Lambwe) included dominant species such as *Oluga* and *Spp. 36*. These species were predominantly found in warmer and drier conditions typical of lower altitudes. The distinct composition at low elevations suggests that these grasses are adapted to rapid growth and heat resilience, which may influence pest interactions in nearby maize farms. Medium-elevation sites(Homabay) showed a different grass composition, with species like *Spp. 16* and *Bothriochloa insculpta*. This category represents a transitional zone, characterized by moderate climatic conditions with sufficient moisture. The grass composition in this elevation may provide a suitable environment for a diverse array of pests, potentially affecting pest dynamics in adjacent maize fields. At high elevations (Vihiga), the grass community was characterized by species such as *Cynadon dactylon*, *Echinochloa pyramidalis*, and *Spp. 13*. These grasses are indicative of cooler and moist conditions typical of higher altitudes. The unique composition at high elevations may contribute to distinct ecological interactions between the grass species and pest populations on neighboring maize farms.

Grasslands at very high elevations (Mt. Elgon) were dominated by species including *Elusine indica, Cyprus immensis*, and *Spp. 5*. These grasses are adapted to cooler climates with ample moisture, conditions that are specific to the highest altitude sites studied. The NMDS plots demonstrated a clear separation of these grass species from lower elevation categories, highlighting the unique ecological environment provided by very high altitudes.

4.1.5 Seasonal and Spatial Variation

The clustering and separation observed in the NMDS plots underscored the significant seasonal and spatial variation in grass species composition across the four elevation categories. These variations are crucial for understanding how grassland composition can influence pest populations, such as stemborer and fall armyworm, in adjacent maize farms. This result aligns with the study's objective of assessing how grass characteristics vary by season and location, emphasizing the role of altitude in shaping grassland diversity and its potential impact on agricultural pest dynamics (Figure 4 and 5 below).

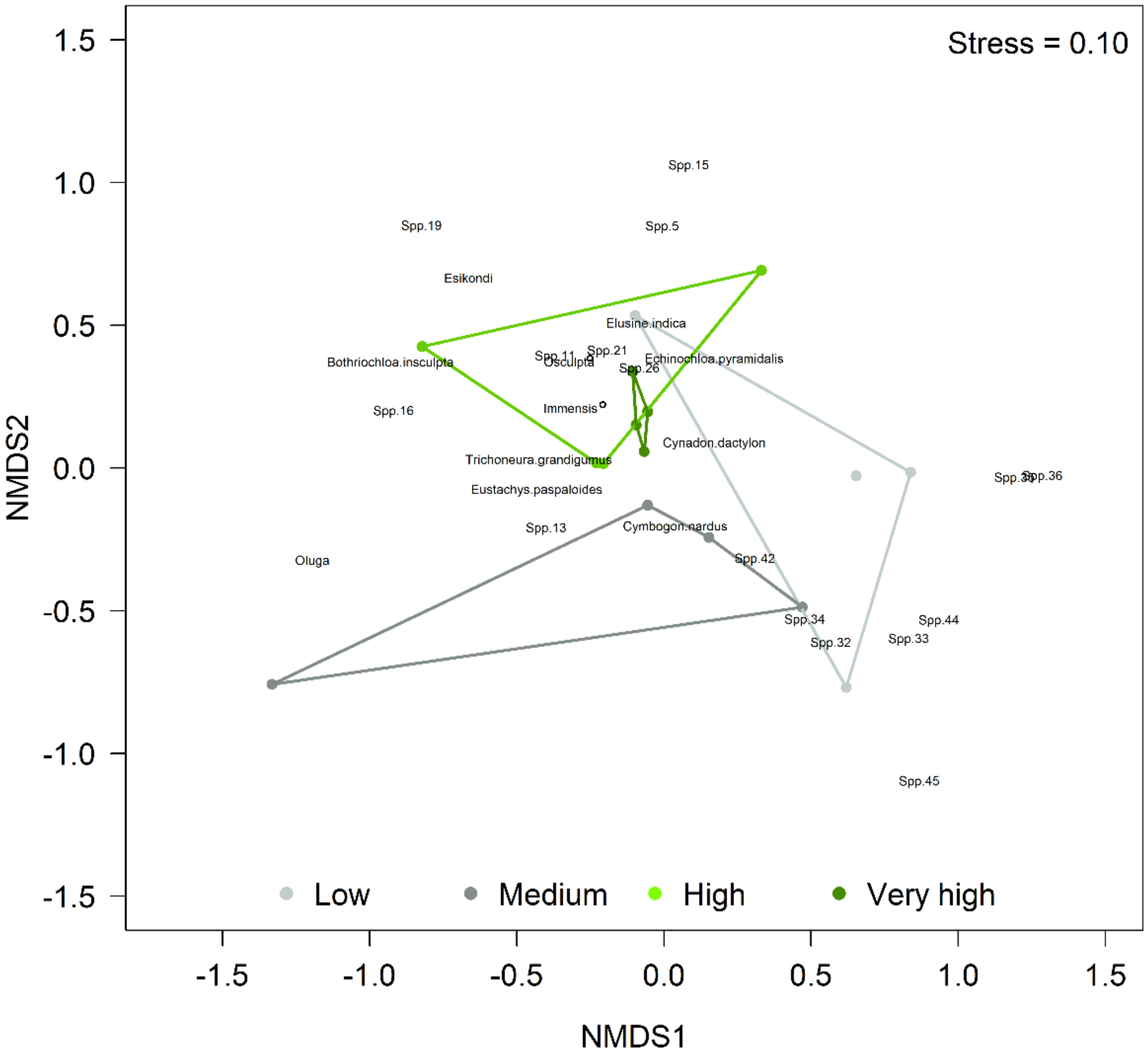

Figure 4: NMDS ordination plot showing the composition of grass species across different altitude categories (Low, Medium, High, Very High) for 2019.

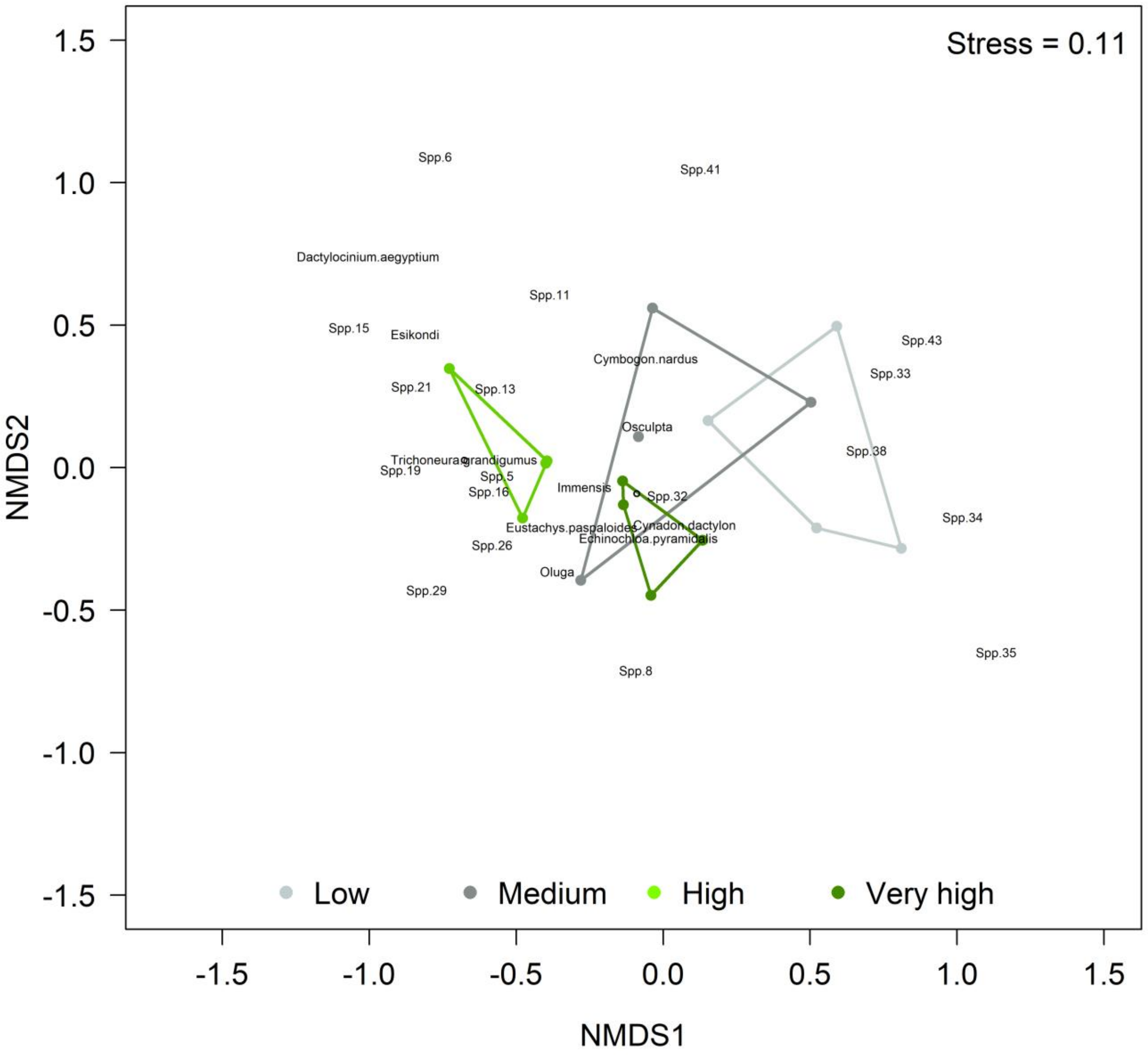

Figure 5 NMDS ordination plot showing the composition of grass species across different altitude categories (Low, Medium, High, Very High) for 2020.

4.1.6 Grass species diversity

The Shannon-Wiener index values in Table 4 represent diversity estimates calculated for different altitude sites during specific rain seasons (Tukey HSD test, α = 0.05).There was no significant difference in diversity among the four elevation sites in 2019. In 2020, Vihiga had significantly lower species diversity than the other three sites. The three sites, Homa bay, Mt Elgon and Lambwe had no significant difference in species diversity.

Table 4: Shannon-Wiener indices for short rain season of 2019 and long rain season of 2020 for the four sites, Vihiga, Homabay, Mt. Elgon and Lambwe. Values are means of three Replications. Means with the same letter in a column are not significantly different

(Altitude (Sites)) masl.	Shannon Wiener index	
	2019	2020
(1400-1600) Vihiga	1.017 a	1.494 a
(1200-1400) Homabay	0.908 a	1.115 b
1600-1800) Mt. Elgon	0.849 a	1.044 b
(1000-1200) Lambwe	0.842 a	0.874 b

Shannon indices, shown letters which are not different; Tukey HSD, α = 0.05.

4.1.7 Grass Percentage Cover and Fresh Weight in Relation to Seasonal Distribution and Characteristics of Grasses Adjacent to Maize Farms in Western Kenya

In 2019, the study aimed to assess the seasonal distribution and characteristics of grasses adjacent to maize farms across four distinct sites in Western Kenya. The results revealed substantial grass coverage in all regions, indicating a generally favorable growing season. Homabay recorded the highest mean grass percentage cover at 91.830 ± 1.458(SE), reflecting dense grasslands, likely influenced by optimal local growing conditions. Mt. Elgon and Lambwe also demonstrated similar dense coverage, with mean values of 89.880 ± 1.379(SE) and 89.370 ± 2.166(SE), respectively. Vihiga, with a mean cover of 90.550 ± 1.385(SE), indicated a consistent and relatively uniform distribution of grass cover across the study sites. This high level of grass coverage suggests that the environmental factors such as rainfall, soil type, and temperature were suitable for grass growth in the 2019 season, contributing to well-maintained grasslands adjacent to maize farms.

The results in 2020 reflected slight variations in grass coverage across the same regions, continuing the focus on understanding seasonal distribution. Mt. Elgon led in percentage cover, with a mean value of 91.012 ± 1.552(SE), indicating dense grassland coverage that persisted from the previous year. Lambwe followed closely with a mean cover of 90.11 ± 2.338(SE), and Homabay and Vihiga exhibited mean percentage covers of 89.97 ± 1.359(SE) and 89.30 ± 1.467(SE), respectively. The relatively consistent grass cover from 2019 to 2020 suggests that the seasonal conditions continued to support high coverage in grasslands adjacent to maize farms. Minimal fluctuations in cover imply stable environmental conditions and resilience in the grass species present.

The assessment of grass characteristics in 2019 included an analysis of biomass, as indicated by the mean fresh weight of grass across the sites. Lambwe exhibited the highest mean fresh weight of 272.490g ± 16.232(SE), suggesting a lush and productive grass environment possibly driven by optimal altitude and soil conditions. In contrast, Mt. Elgon recorded the lowest mean fresh weight at 69.510g ± 6.711(SE), highlighting differences that might be attributed to local factors such as species composition, soil fertility, and microclimate. Homabay and Vihiga had intermediate biomass values, with mean fresh weights of 142.070g ± 6.711(SE) and 108.880g ± 6.65(SE), respectively, indicating moderate productivity. These variations in biomass across the sites in 2019 provide insights into the diverse environmental conditions influencing grass growth and productivity. The graph below Figure 6, illustrates the average grass percentage cover and fresh weight for 2019 across four study sites at different altitudes in western Kenya. The green bars represent the mean grass percentage cover, with error bars indicating the standard error for each location. The blue bars display the mean grass fresh weight, also accompanied by error bars showing the standard error.

The biomass assessment in 2020 showed noticeable differences from the previous year, indicating changes in grass productivity across the sites. Lambwe demonstrated the highest mean fresh weight, increasing to 317.46g ± 22.527(SE), suggesting continued high productivity and potentially improved growing conditions or species composition. Homabay also showed a substantial increase in biomass to 219.020g ± 14.026(SE), reflecting better conditions compared to 2019. Mt. Elgon, despite having the highest percentage cover, exhibited a lower mean fresh weight of 117.240g, Figure 7 below. These findings underscore the influence of seasonal and local environmental conditions, such as rainfall patterns, temperature variations, and soil quality, on grass characteristics adjacent to maize farms in Western Kenya.

The results highlighted a consistent and dense grass cover in both years across different regions, with variations in biomass suggesting nuanced local environmental influences. These insights are critical in understanding the seasonal distribution and characteristics of grasses, which play a crucial role in the agroecosystem dynamics around maize farms.

This visualization helps to compare the seasonal and spatial differences in grass characteristics across varying elevations adjacent to maize farms.

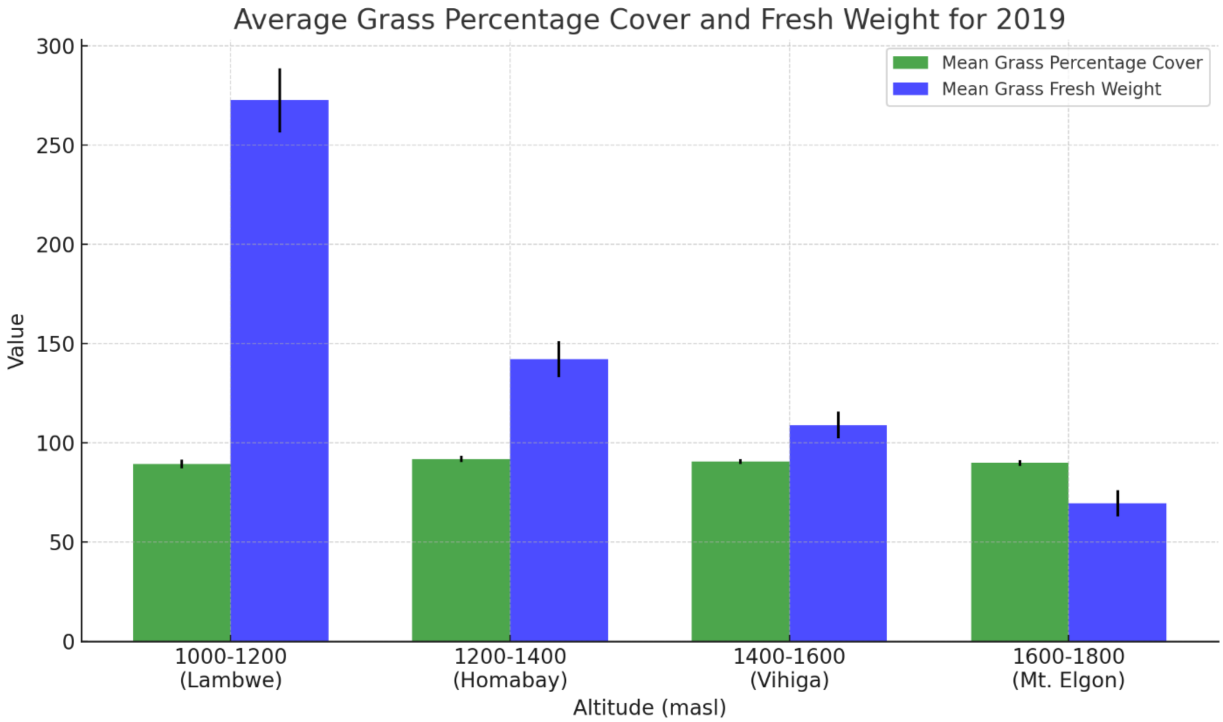

Figure 6: Grass percentage cover and fresh weight during the long rain season of 2019(Error bars represent values of standard errors).

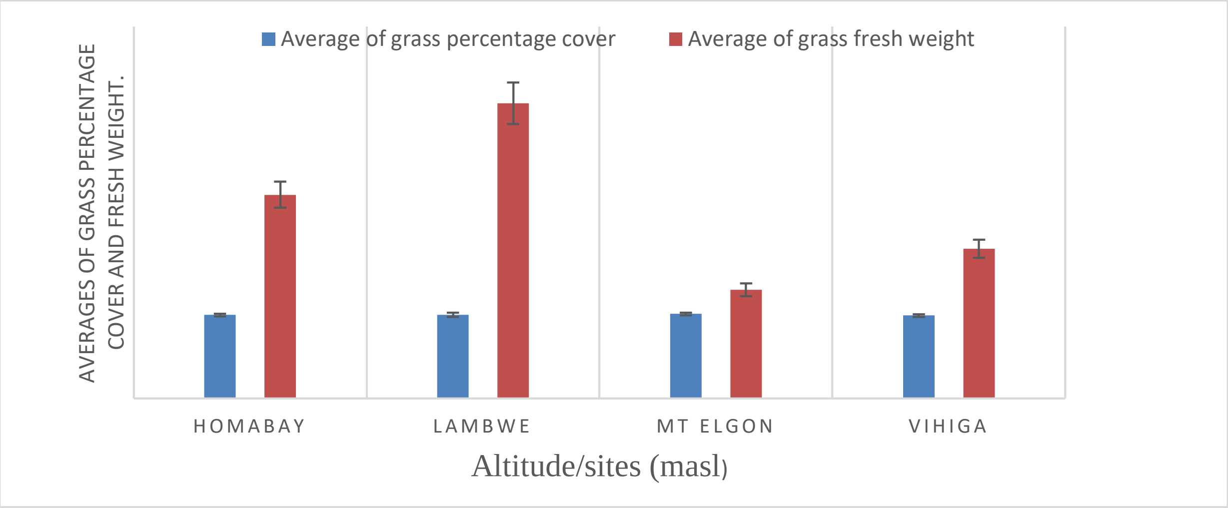

Figure 7: Grass percentage cover and fresh weight during the long rain season of 2020 (Error bars represent values of standard errors).

4.2 Examining the impact of altitude variation on grass species diversity and the population of stemborers and fall armyworm in 2019 and 2020 across the four varying altitude

4.2.1 Effect of altitude on grass species richness and diversity

The generalized linear model results illustrate the impact of altitude on grass species richness and diversity in 2019 and 2020, highlighting significant differences among altitude groups. In 2020, the reference group (1200-1400 masl) exhibited the highest richness/diversity (IRR: 7.563), while the 1000-1200 masl group showed a significant reduction (IRR: 0.727). Although not statistically significant, trends in the 1600-1800 masl group suggested lower diversity (IRR: 0.785), and the 1400-1600 masl group indicated similar richness compared to the reference. In 2019, the 1200-1400 masl group also displayed high richness (IRR: 5.188), with the 1000-1200 masl group showing no significant difference. Notably, the 1400-1600 masl group showed a significant increase in richness (IRR: 1.361). These variations in grass species diversity across altitudes may influence the populations of stemborers and fall armyworms, as higher diversity at certain altitudes could provide more habitat and resources for these pests, potentially increasing their populations. Conversely, lower species richness at certain altitudes may limit suitable host plants, leading to reduced pest densities. Understanding these ecological interactions is vital for managing pest dynamics in regions like Lambwe, Homabay, Vihiga, and Mt. Elgon.

The data in Table 5 illustrates the impact of altitude variation on grass species richness and diversity across different sites in western Kenya (Lambwe, Homabay, Vihiga, and Mt. Elgon) during the 2019 and 2020 cropping seasons. The focus is on examining how changes in altitude influence grass species diversity, which in turn may have implications for stemborer and fall armyworm populations, given their reliance on specific grass habitats.

Table 5: Generalized linear model results of effects of altitude on grass species richness and diversity in 2019 and 2020.

Altitude	2020			2019		
	Estimates	**Pr (>|z|)**	**IRR**	**Estimates**	**Pr (>|z|)**	**IRR**
Intercept(1200-1400masl)	2.023	16***	7.563	1.646	16***	5.188
1000-1200masl	0.318	0.0230*	0.727	-0.128	0.424	0.880
1600-1800masl	0.242	0.078	0.785	0.146	0.332	1.157
1400-1600masl	0.167	0.176	1.182	0.309	0.0328*	1.361

4.2.2 Effect of altitude on stemborers and fall armyworms on grasses surrounding maize farms in Lambwe, Homabay, Vihiga and Mt. Elgon

The Chi Square test (Table 6) indicate that altitude had no significant effect on the stemborers and fall armyworms found on the grasses in the four sites, (*P* = 0.9165 and *3, P* = 0.9609), respectively for 2020 and 2019 seasons. For 2020, high altitude had the highest estimated effect (1.20) on pest abundance with a very significant p-value (<0.001) and an IRR of 3.32. Low altitude in 2020 shows a moderate increase with an IRR of 1.65. Similar trends were observed in 2019, with high altitude showing the highest IRR.

Table 6: Effects of altitude on the abundance of stemborers and fall armyworms on grasses

	2020			2019		
Sites	Estimates	Pr (>|z|)	IRR	Estimates	Pr (>|z|)	IRR
Intercept(Vihiga)	1.002	<2e-16***	2.725	1.025	<2e-16***	2.788
Lambwe	0.058	0.535	1.060	0.044	0.636	1.045
Homabay	0.058	0.540	1.050	0.031	0.742	1.031
Mt. Elgon	0.045	0.636	1.046	0.044	0.640	1.045

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘’ 1

4.2.3 Effect of altitude on fall armyworms on maize farms in Lambwe, Homabay, Vihiga and Mt. Elgon

Table 7 indicates that altitude significantly influenced the abundance of fall armyworm on maize farms across the four sites during both the 2020 and 2019 seasons (P = 2.2 e-16*** for both years).

Table 7: Effects of altitude on the abundance of fall armyworm on maize farms

	2020			2019		
Sites	Estimates	Pr (>|z|)	IRR	Estimates	Pr(>|z|)	IRR
Intercept	3.045	<2e-16***	21.000	3.604	<2e-16***	36.750
Lambwe	-0.742	0.000112***	0.476	-1.464	1.4e-14***	0.231
Homabay	0.204	0.165438	1.226	-0.502	0.0002***	0.605
Mt. Elgon	-1.486	4.9e-09***	0.226	-0.014	0.906827	0.986

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

4.3 Exploring the influence of grass composition and grass characteristics on population of stemborers and fall armyworms on grasses surrounding maize farm in 2019 and 2020

4.3.1 Stemborers and fall armyworms abundance on the grass

After calculating the percentage of each category in both years and the increase or decrease in each category from 2019 to 2020, the following was obtained (Table 8)

Table 8: Percentage of larvae and moths recovered on the grass in 2019 and 2020.

Category	2019 count	2019 %ge	2020 count	2020 %ge
frugiperda moth	4	11.11	1	2.27
C. partellus moth	0	0	1	2.27

C. partellus larvae	10	27.78	12	27.27
frugiperda larvae	22	61.11	30	68.18

This table shows that while the total number of pests increased from 2019 to 2020, the number of *frugiperda* moths decreased. However, the number of *frugiperda* larvae significantly increased, indicating a possible preference for grasses. Furthermore, some of the fall armyworm pests prefer grasses, (Plate 17). Most likely they diapause eggs on the soil under the grasses. The preference of fall armyworm (*Spodoptera frugiperda*) for grasses, was established through various methods and observations in agricultural research and entomology. Here's how this preference is typically established:

Plate 9 : Fall armyworm found under the grasses in the quadrates (00°05'598"N, 034°35'628"E) (photo taken by Nelima, Maryselah).

4.3.2 Effect of grass diversity and its characteristics on the population of stemborers and fall armyworm on grassland surrounding maize farms in 2019 and 2020

Figure 8 and 9 below depict principal component analysis (PCA) and non-metric multidimensional scaling (NMDS) ordination of impact of grass diversity and various environmental factors on the population dynamics of stemborers and fall armyworms in grassland areas surrounding maize farms. In 2019, (Principal Components (PCs) 1 and 2 collectively accounted for 64.64% of the total variation, while in 2020, they explained 54.51%. PC1 included variables such as elevation, disturbed quadrats, borers per quadrat, rainfall, and volume, with volume showing a negative correlation with the other variables in both years, indicating an inverse relationship. PC2 encompassed percentage grass cover in the landscape and relative humidity (RH), which exhibited negative correlations with other variables.

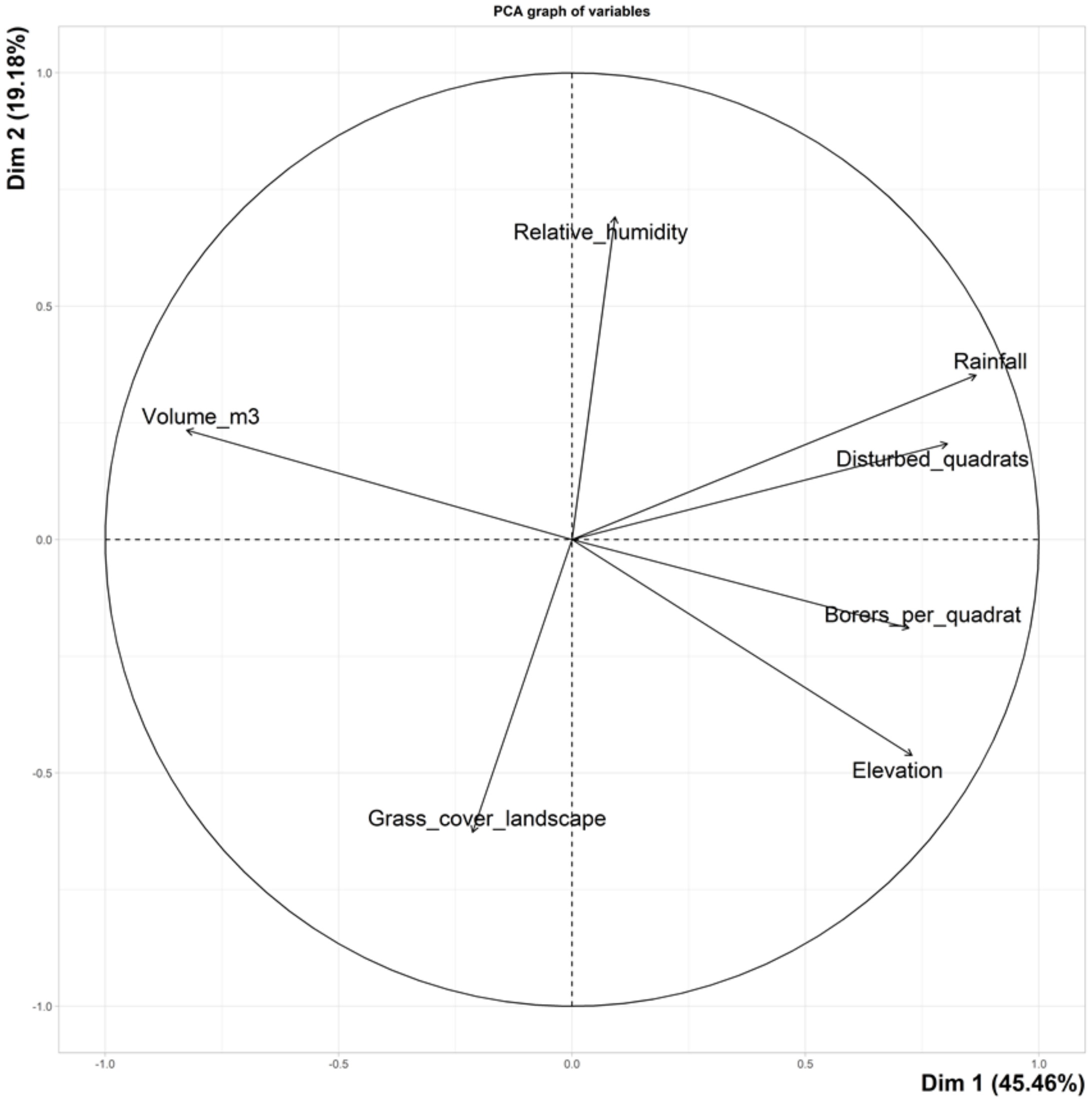

Figure 8: Fitting Environmental variables to the NMDS ordination space for 2019.

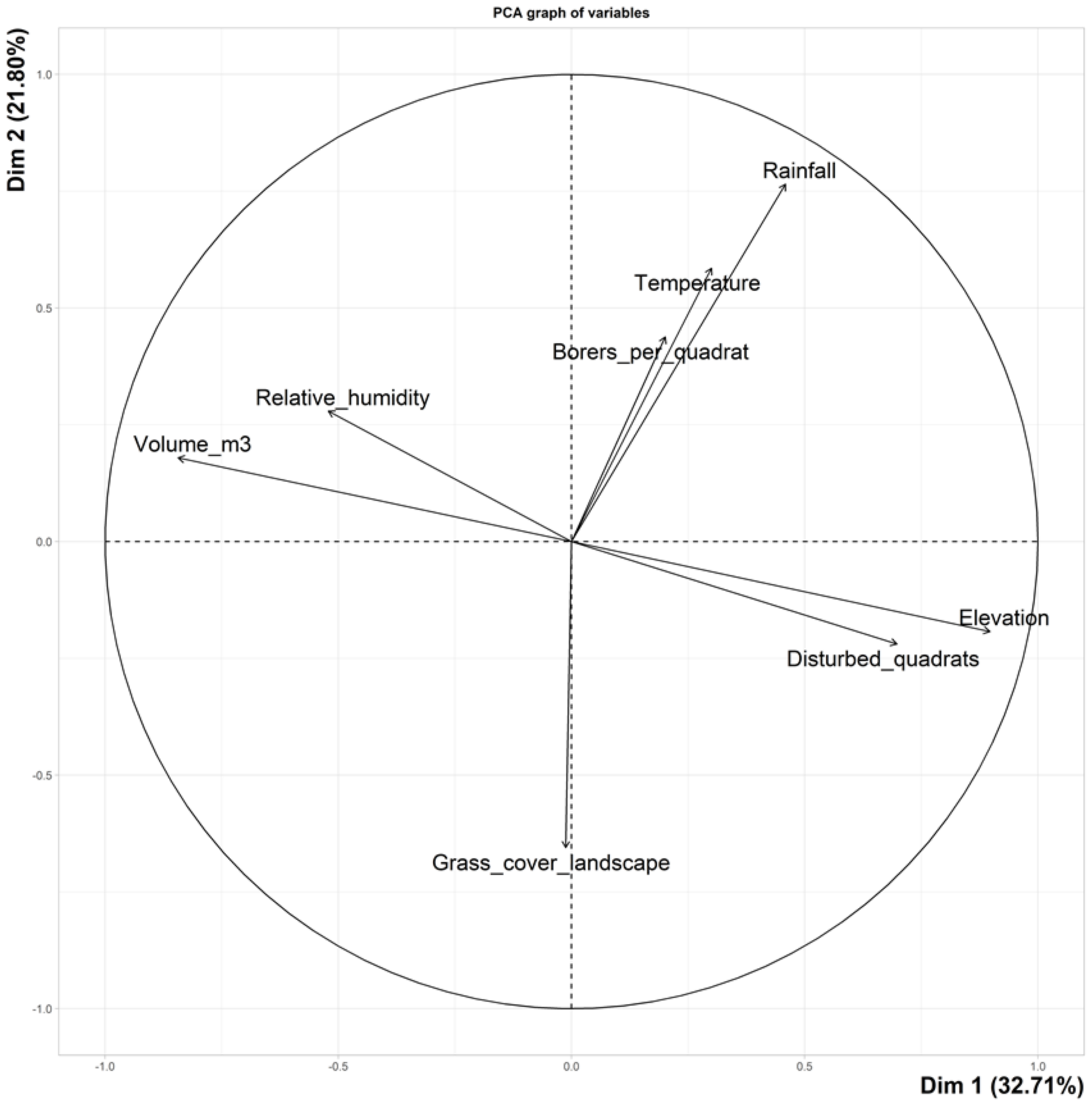

Figure 9: Fitting Environmental variables to the NMDS ordination space for 2020

The PCA analysis revealed that there is no correlation between percentage grass cover and elevation in both years, indicating that elevation does not directly affect the amount of grass cover. However, a positive correlation was observed between disturbed quadrats and elevation, suggesting that higher elevations might experience more disturbance. These findings are supported by the PCA biplots and calculated correlation coefficients.

4.3.3 NMDS Ordination

Environmental variables such as rainfall, relative humidity, volume (m3), proportion of disturbed quadrats, proportion of damage, and borers per quadrat were fitted into the NMDS ordination space for 2019 and 2020. The contribution of each variable to NMDS1 and NMDS2, along with the coefficient of determination (R2) and P-value are shown. In 2019, Rainfall moderately influenced the data ($R^2 = 0.325$), not statistically significant ($P = 0.083$). Relative Humidity had low influence ($R^2 = 0.131$), not statistically significant ($P = 0.390$). Volume of Grass (m^3) had high influence ($R^2 = 0.567$), statistically significant ($P = 0.004$). Proportion Disturbed Quadrats moderately influenced the data ($R^2 = 0.321$), not statistically significant ($P = 0.078$). Proportion Damage had low influence ($R^2 = 0.116$), not statistically significant ($P = 0.444$). Borers per Quadrat had moderate to high influence ($R^2 = 0.498$), statistically significant ($P = 0.012$).

In 2020, rainfall had moderate influence ($R^2 = 0.504$), statistically significant ($P = 0.013$). Relative Humidity had low influence ($R^2 = 0.112$), not statistically significant ($P = 0.453$). Temperature had very low influence ($R^2 = 0.056$), not statistically significant ($P = 0.692$). Volume of Grass (m^3) had high influence ($R^2 = 0.664$), statistically significant ($P = 0.001$). Proportion Disturbed Quadrats had low influence ($R^2 = 0.151$), not statistically significant ($P = 0.330$). Proportion Damage had very low influence ($R^2 = 0.007$), not statistically significant ($P = 0.954$). Borers per Quadrat had very low influence ($R^2 = 0.001$), not statistically significant ($P = 0.989$).

Table 9: Results of fitting environmental variables to the NMDS ordination space.

	NMDS1	**NMDS2**	**R^2**	***P***
2019				
Rainfall	-0.771	0.637	0.325	0.083
Relative humidity	-0.543	-0.840	0.131	0.390
Volume of grass (m^3)	0.597	-0.803	0.567	**0.004**
Proportion disturbed quadrats	-0.723	0.691	0.321	0.078
Proportion damage	0.502	0.865	0.116	0.444
Borers per quadrat	-0.868	0.497	0.498	**0.012**
2020				
Rainfall	-1.000	0.021	0.504	**0.013**
Relative humidity	0.283	-0.959	0.112	0.453
Temperature	-0.953	0.302	0.056	0.692
Volume of grass (m^3)	0.900	0.436	0.664	**0.001**
Proportion disturbed quadrats	-0.672	-0.740	0.151	0.330
Proportion damage	-0.063	-0.998	0.007	0.954
Borers per quadrat	-0.974	0.225	0.001	0.989

The graph below (Figure 9) presents Spearman's rank correlation (Rs) values that illustrate the relationships between various grass characteristics and pest populations across different altitudes and seasons, specifically during the short rains of 2019 and the long rains of 2020.

Firstly, both dry weight and grass volume exhibit a strong positive correlation with pest populations in all locations, particularly in Lambwe and Mt. Elgon. This indicates that increases in dry weight and grass volume are associated with higher pest abundance across both seasons. In contrast, grass percentage cover shows a negative correlation in all locations, most notably in Homabay and Vihiga, suggesting that denser grass cover was linked to lower pest populations. This implies that increased grass coverage may help reduce pest presence on maize farms.

Rainfall reveals a strong positive correlation with pest populations in Vihiga and Lambwe, while a moderate or mixed correlation was observed in other regions. This finding indicates that higher rainfall generally promotes pest abundance, especially in specific altitudinal locations. Temperature correlations vary across locations; for instance, Vihiga and Homabay display a moderate positive correlation with pest populations, while other areas exhibit more correlations that are neutral. This variability suggests that temperature influences pest populations differently depending on altitude.

Additionally, disturbed quadrats showed strong negative correlations in Vihiga, Homabay, and Lambwe, particularly in 2020, indicating that disturbances such as those caused by human or animal activity were associated with lower pest populations in these areas. The abundance of the grass species *Cyprus immenss* is correlated negatively with pest populations in most locations, especially in Vihiga and Mt. Elgon, suggesting that this species may not support pest survival or proliferation. Conversely, *Cynadon dactylon* abundance is positively correlated with pest populations in Mt. Elgon and Lambwe, indicating that this species may provide a favorable habitat or resources for pest development, particularly in higher altitude regions.

The results highlighted that the correlation between grass characteristics and pest populations was influenced by both altitude and seasonal conditions. Characteristics such as grass cover and rainfall exhibit a more consistent impact across locations, while factors like temperature and species-specific abundance display greater variability in their correlations with pest populations.

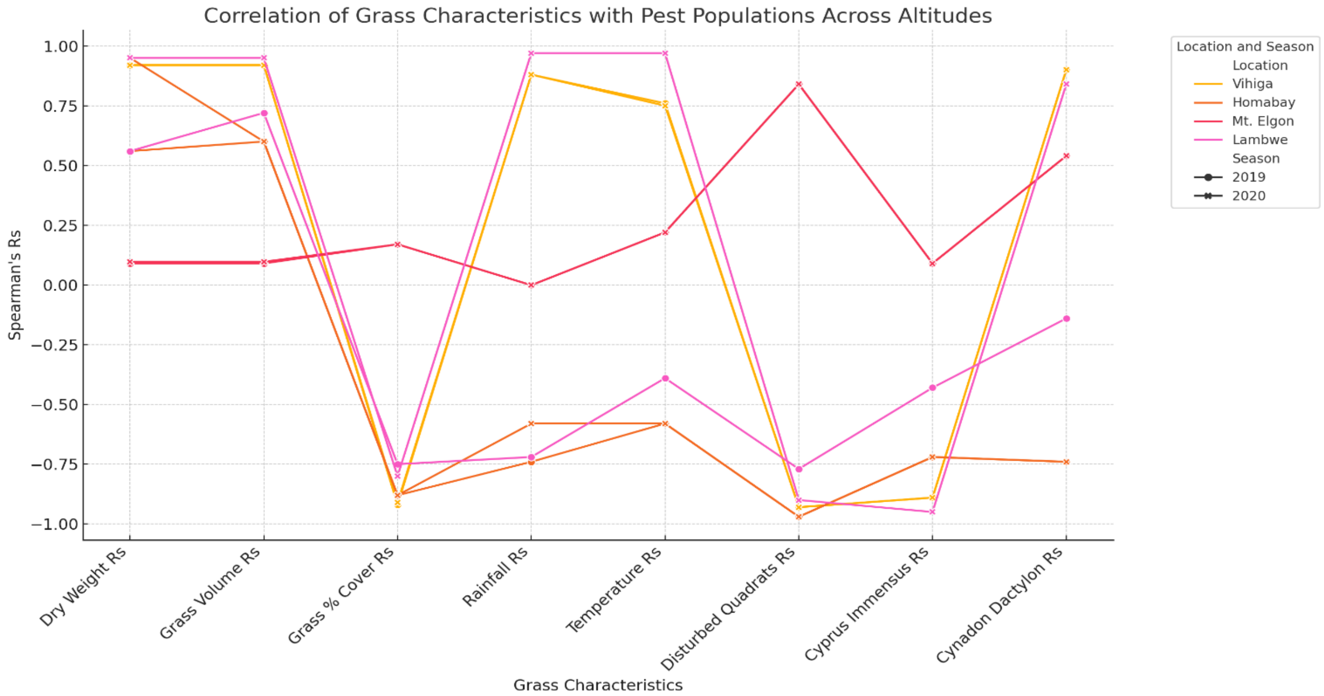

Figure 10: Correlation of Grass Characteristics with Pet Populations Across Altitudes

4.4 Effect of grass composition and its characteristic on the population of stem borers and faw in maize fields in 2019 and 2020

4.4.1 Stemborers and fall armyworms on maize farms.

Table 8 below presents the average abundance of fall armyworm (*Spodoptera frugiperda*) observed on 16 maize farms in 2019 and 2020. Across both years, fall armyworm presence was noted on all farms, with variation in abundance per farm. The incidence of stemborers on maize farms was negligible and thus excluded from analysis. The fall armyworm invasion was marked by visible plant damage in the maize fields, as shown in Plate 18. Table 13 further details the average abundance of fall armyworm per farm, with each row corresponding to an individual farm's observation in both years.

Plate 13: showing a damaged plant by a fall armyworm in the maize farm; (00°36'720"S, 034°29'695"E) (photo taken by Nelima, Maryselah).

Table 9: Fall Armyworm Abundance on Maize Farms (2019 and 2020) in Percentage Form

Farm	GPS Coordinates	2019 Abundance (%)	2020 Abundance (%)	Percentage Change
Nactical	-00°04'59"N 034°34'604"E	2.23%	0.00%	-100.00%
Chelamba	00°05'598"N 034°35'628"E	9.70%	20.44%	115.38%
Patrick	-00°01'667"N 034°33'980"E	79.10%	11.68%	-85.05%
Jairus	00°00'399"N 034°35'332"E	17.75%	29.20%	66.67%
Agnes	00°47'452"N034°29'119"E	60.82%	13.87%	-76.83%
Kapule	00°48'297"N 034°29'286"E	17.75%	0.00%	-100.00%
Laban	00°48'846"N 034°29'988"E	7.41%	0.00%	-100.00%
Moses	00°48'745"N034°29'791"E	21.48%	0.00%	-100.00%
Angeline	00°38'501"S034°30'980"E	2.23%	22.63%	933.33%
Reuben	00°36'720"S 034°29'695"E	31.85%	20.44%	-34.88%
Pamela	00°37'769"S034°29'642"E	11.85%	0.00%	-100.00%
Domnicus	00°35’420’’S 034°25’953’’E	20.00%	32.12%	62.96%
Oyoo	00°34'422"S034°19'203"E	8.15%	13.14%	63.64%
Mary	00°33'698"S034°18'963"E	0.00%	16.06%	0.00%
Otieno	00°00'163"S034°35'954"E	6.67%	0.00%	-100.00%
Sanaa	00°33'551"S034°18'242"E	10.37%	4.38%	-57.14%

4.4.2 Effect of grass characteristics on the population of faw and stemborers on maize farms

The correlation analysis of grass characteristics with FAW and stemborer populations on maize farms reveals several trends across locations and seasons. For dry weight and volume of grass, a moderate to high positive correlation is observed in all locations, indicating that higher dry weight and grass volume are associated with increased pest populations. Grass percentage cover, however, shows a strong negative correlation in locations like Homabay and Vihiga, suggesting a potential reduction in pest presence with increased grass cover. Table 16 in the appendix displays the correlation coefficients (rs) and corresponding p-values (p) assessing the relationship between various grass characteristics and the populations of fall armyworm (FAW) and stemborers on maize farms during the short rain season of 2019 and the long rain season of 2020 across different locations (Vihiga, Homabay, Mt. Elgon, Lambwe).

Rainfall correlations vary by location, with Vihiga showing a strong positive correlation, while other locations display moderate or mixed results. Temperature correlations are inconsistent across locations, with both positive and negative values observed, indicating that temperature may impact pest populations differently depending on the region. Disturbed quadrats show a consistently strong negative correlation, particularly in Homabay and Vihiga, suggesting that disturbances may be associated with reduced pest populations.

Regarding specific grasses, *Cyprus immensis* abundance generally has a negative correlation with pest populations, while *Cynadon dactylon* abundance shows a positive correlation, especially in Mt. Elgon. Seasonal variations are also evident, with some correlations, particularly for rainfall and disturbed quadrats, showing differences between 2019 and 2020. This indicates that seasonal factors may influence the relationship between grass characteristics and pest populations on maize farms, as shown in graph below.

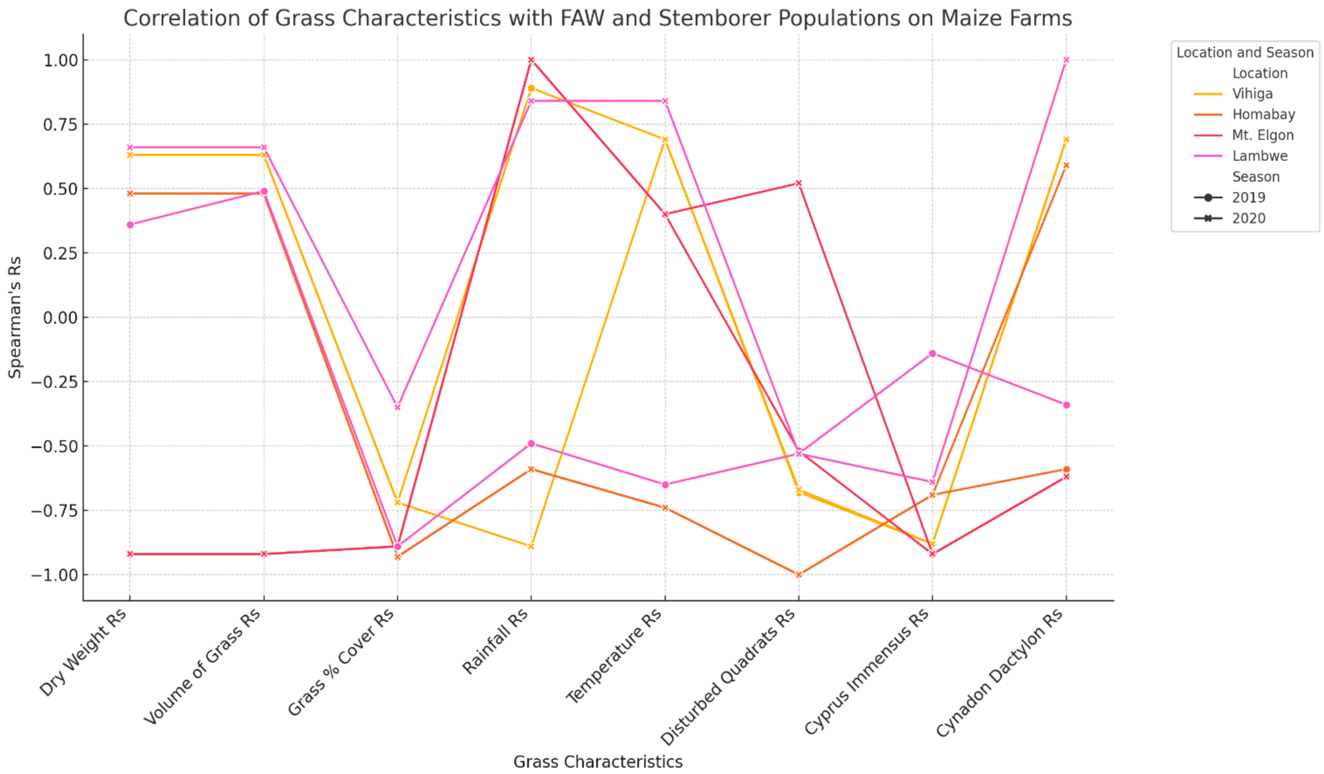

Figure 11: Correlation of Grass Characteristics with FAW and stemborer populations on Maize farms

CHAPTER FIVE

DISCUSSION

5.1 Grass Composition per Sites(altitudes)

The analysis of grass species composition across the four study sites Lambwe, Homabay, Mt. Elgon, and Vihiga during the years 2019 and 2020 highlights distinct seasonal and altitudinal influences on species richness, composition, and dominance, aligning with findings from previous studies on grassland dynamics. Generally, species richness increased across all sites from 2019 to 2020, supporting prior research which demonstrates that species diversity often peaks in wetter seasons due to increased resources and favorable growing conditions (Hodgson et al., 2018). This seasonal dynamic aligns with the findings in Lambwe, where species richness rose from 1.52 in 2019 to 1.70 in 2020, alongside a marked increase in the dominance of *Cynodon dactylon* and *Cyperus immensis*. The shift in dominance highlights the adaptability of *Cynodon dactylon*, a grass well-documented for its resilience and competitive edge in diverse environments (Smith & Westoby, 2018), as well as Cyperus immensus, known for its ability to thrive in moist, seasonally influenced habitats (Wang et al., 2020).

In Homabay, although species richness saw a moderate increase from 1.65 in 2019 to 1.78 in 2020, the changes in dominant species, from *Elusine indica* to *Echinochloa pyramidalis*, underscore the variability in grass species prevalence across seasons. *Elusine indica*, which was prominent in 2019, decreased in proportion as *Echinochloa pyramidalis* became more abundant in 2020, suggesting that these species may have varying responses to seasonal changes or interspecies competition. Similar observations were made by Fynn et al. (2018), who found that rainfall and seasonal shifts in soil moisture are critical factors driving species turnover in grasslands, especially in altitude regions like Homabay.

Higher-altitude sites like Mt. Elgon exhibited a more pronounced increase in species richness, from 1.79 in 2019 to 2.02 in 2020, with significant shifts in dominant species from *Spp 44* in 2019 to *Spp 33* in 2020. The change in dominant species at this site aligns with studies suggesting that altitude gradients create microclimates that influence species composition and favor certain grasses adapted to cooler, high-altitude conditions (Beierkuhnlein et al., 2019). The observed increase in species richness and shift in dominance may also relate to reduced competition at higher altitudes, allowing more grass species to establish and flourish. Such findings are consistent with research by Chapman et al. (2017), who observed that high-altitude grasslands often support a diverse array of species with specialized ecological niches, particularly during wetter seasons.

In Vihiga, a similar pattern of seasonal and altitudinal dynamics was observed, with species richness increasing from 1.95 in 2019 to 2.19 in 2020. The dominant species also shifted significantly, with *Cymbon nardus* becoming the most abundant in 2020, replacing *Pilgrimis spp*, which had a lower abundance in 2019. These shifts further illustrate the influence of seasonal rainfall on grass composition, as well as potential interspecies competition and resilience to disturbances, as highlighted in studies by Morris et al. (2019) and Fritz et al. (2021), which discuss how certain grasses, like *Cymbon nardus*, thrive under variable moisture conditions and are often more prevalent in disturbed grasslands.

These findings collectively emphasize that the seasonal composition, distribution, and characteristics of grass species in grasslands adjacent to maize farms in western Kenya are closely linked to altitude and seasonal rainfall. The variations in species richness and dominance across sites and years mirror broader ecological patterns observed in grassland studies, indicating that both seasonal changes and altitude-related microclimatic conditions play crucial roles in shaping grassland biodiversity and ecosystem functions. Understanding these dynamics is essential for sustainable land management, particularly in agricultural regions where grasslands serve as buffer zones and habitats for pest-predating species.

5.1.1 Grass species richness

The results reveal significant differences in grass species richness, abundance, and composition between seasons and across the four study sites with varying altitudes, demonstrating how environmental factors influence grassland species composition adjacent to maize farms. In 2020, during the long rains, 55 grass species were identified compared to 32 species during the short rains in 2019, suggesting that seasonal rainfall impacts grass species richness and composition.

This pattern aligns with previous studies on seasonal grassland dynamics, which have shown that higher rainfall seasons typically support greater species diversity and abundance due to improved moisture availability for plant growth (Hodgson et al., 2018; Chapman et al., 2017). The long rains promote germination and growth, especially for annual and opportunistic grasses, which are more abundant during these wetter months.

In terms of specific grass species, *Cynodon dactylon* and *Cyperus immensis* consistently appeared among the most abundant species across both years and multiple locations, though their ranks varied slightly by site and season. *Cyprus immensis* spp and *Cynadon dactylon* were the most common species, showing high abundance during the 2019 and 2020 rainy seasons. Grass species richness in 2019 varied significantly across different altitudes and climatic conditions in Lambwe, Homabay, Vihiga, and Mt. Elgon. Vihiga exhibited the highest species richness, attributed to favorable climatic conditions such as high rainfall at mid-altitudes (1400-1600 masl), which support diverse grass growth. In contrast, Lambwe had the highest mean fresh weight, indicating greater primary productivity. Mt. Elgon, at a very high altitude (1600-1800 masl), and Lambwe and Homabay had lower species richness compared to Vihiga, reflecting the influence of altitude and climate on grassland biodiversity and productivity. Their prevalence supports findings from related studies that suggest certain grass species are more competitive and adaptive to environmental stressors, such as grazing pressure and soil variation in grasslands (Morris et al., 2019). *Cynodon dactylon*, in particular, is well-documented as a resilient grass capable of thriving in various climates, supporting previous research on its ecological adaptability and its role as a dominant species in disturbed and grazed environments (Smith & Westoby, 2018). *Cyperus immensis* also showed high abundance, particularly in Mt. Elgon and Lambwe, which is consistent with research indicating that certain *Cyperus* species favor high-altitude and moist environments, where they can proliferate and compete effectively with other grasses (Wang et al., 2020).

The observed site-specific differences in grass species composition and rank may be influenced by altitude, temperature, and soil type, as suggested by previous research on grassland ecosystems. Studies by Fynn et al. (2018) and Beierkuhnlein et al. (2019) confirm that altitude gradients create microclimates that affect grass species distribution, with certain species adapted to cooler, higher elevations (such as Mt. Elgon) compared to the warmer, low-altitude sites like

Homabay. These findings align with the high abundance of *Cyperus immensis* in Mt. Elgon, which is characteristic of high-altitude-adapted species that can tolerate cooler temperatures and different soil profiles. The differences in results between 2019 and 2020 regarding grass species diversity, where it was significant in 2019 but not in 2020, could indicate variations in environmental conditions or other factors affecting grass diversity across these years. It's important to acknowledge that factors beyond altitude may have influenced grass species diversity in 2020, leading to differences in significance compared to 2019. Other environmental variables, seasonal variations, or changes in land use practices could contribute to these differences. Contrary to expectations, it has been suggested that the functional reduction of many grass species may have little effect on ecosystem function (Cowling, 1990). Our findings showed differences in grass species richness, fifty-five (55) grass species were identified in 2020, during the long rain season and 32 grass species in 2019 during the short rain season, grass abundance, and fresh weight of grasses surrounding maize fields across the four elevations in both 2019 and 2020. These results lead us to reject the null hypothesis that there is no significant difference in grass species richness among the four sites. The observations on grass species richness influenced by altitude-related climatic factors in Lambwe, Homabay, Vihiga, and Mt. Elgon align with findings from previous ecological studies examining the impact of altitude and climate on plant biodiversity. Similar research has shown that altitude gradients create distinct microclimates, which significantly affect plant species composition and ecosystem productivity. Körner, (2007) studied “The use of 'altitude' in ecological research," in which the study emphasized that altitude gradients lead to variations in temperature and moisture availability, which in turn affect species richness and ecosystem productivity. Higher altitudes typically exhibit lower temperatures and different moisture regimes, which influence plant community composition similarly to the findings in Vihiga and Mt. Elgon. Rahbek's research, (Rahbek, 2005) on "The role of spatial scale and the perception of large-scale species-richness patterns," highlighted that mid-altitudinal ranges often support higher biodiversity due to a balance of favorable climatic conditions, such as adequate rainfall and moderate temperatures. This aligns with the higher species richness observed in Vihiga. Cuesta *et al*., (2017) in their study on "Plant species richness along an altitudinal gradient in the Andes of northern Argentina, found that mid-altitudes exhibited the highest plant species richness, similar to Vihiga's biodiversity. They attributed this to optimal growing conditions, comparable to the role of high rainfall in Vihiga.

In conclusion, the species composition and richness across seasons and altitudes reflect the dynamic relationship between grassland characteristics and environmental factors, especially rainfall and altitude. The grassland adjacent to maize farms in these regions supports diverse species, with seasonal variations that likely influence pest populations and ecosystem services on nearby maize farms. This aligns with broader ecological studies that highlight the importance of understanding grass species composition in managing pest dynamics and promoting sustainable agriculture (Fritz et al., 2021).

5.1.2 Grass species distribution

The results from the Non-Metric Multidimensional Scaling (NMDS) and Permutation Multivariate Analysis of Variance (PERMANOVA) illustrate how grass species distribution and composition are significantly influenced by altitude in the study sites of western Kenya. Similar studies underscore the complex interactions between altitude, seasonal variation, and grass species adaptation, impacting grassland composition and adjacent agricultural ecosystems, particularly maize farms. Here's how these findings align with and add to existing research.

Altitude and Grass Species Distribution: The NMDS plots and PERMANOVA results reveal clear altitudinal stratification of grass species across low (Lambwe), medium (Homabay), high (Vihiga), and very high (Mt. Elgon) elevations, with notable statistical differences across these elevation groups, particularly in 2020. The significant differences in species composition observed ($P < 0.05$ for very high vs. high and high vs. low) support findings by Ndungu et al. (2019), who documented similar altitudinal effects on grass species diversity and abundance across western Kenya's variable landscape. Grass species composition at higher elevations, such as at Mt. Elgon, is distinct from that at lower sites, suggesting that the cooler temperatures and higher moisture levels favor different species. For example, species like *Elusine indica* and *Cyprus immensis* are more prevalent at very high altitudes, supporting Kibet et al. (2020), who observed similar patterns in high-altitude grasslands.

Low Elevation (Lambwe): Grass species like *Oluga* and *Spp. 36*, adapted to warmer and drier conditions typical of Lambwe's low-altitude environment, were prevalent. This grass composition aligns with previous studies Kamau & Nyangito. (2018) that indicate low-altitude grasslands are often dominated by species tolerant of rapid growth and heat, contributing to pest dynamics in nearby maize farms. Such environments provide breeding grounds for pests like the fall armyworm due to reduced competition and a suitable microhabitat, which are factors critical for pest control strategies in lower-altitude agricultural zones.

Medium Elevation (Homabay): Medium-altitude areas, characterized by transitional grass species like *Spp. 16* and *Bothriochloa insculpta*, reflect moderate climatic conditions with adequate moisture. This transitional zone has been shown to harbor diverse insect populations, particularly pests that migrate from surrounding grasslands into maize fields. As observed by Odongo et al. (2018), grasslands in such zones facilitate a habitat continuum that supports pest life cycles, impacting agricultural productivity.

High Elevation (Vihiga): At high altitudes, species like *Cynodon dactylon*, *Echinochloa pyramidalis,* and *Spp. 13* dominate, indicating a preference for the cooler and moist conditions. Previous studies, such as that by Karue et al. (2019), emphasize that grass species in high-altitude zones serve as critical habitats for natural predators of maize pests. For example, *Cynodon dactylon*, documented for its adaptive resilience, is associated with beneficial insects, which can potentially control pest populations in nearby maize farms.

Very High Elevation (Mt. Elgon): The species composition at very high altitudes, dominated by *Elusine indica*, *Cyprus immensis*, and *Spp. 5*, differs significantly from lower-altitude compositions, illustrating how unique climatic conditions shape grass diversity. High-altitude grasslands, as noted by Wainaina et al. (2020), support species adapted to cold, moist conditions, which do not thrive at lower elevations. This biodiversity creates a distinct ecological structure in very high altitudes, contributing to pest control benefits for adjacent maize farms by limiting the spread of species that could support pest populations.

Seasonal and Spatial Variation: The clustering patterns in the NMDS plots for 2019 and 2020 reflect significant seasonal and spatial variability in grass species composition across altitudes. The shift in seasonal composition, influenced by rainfall and temperature changes, aligns with the work of Mutiso and Kinuthia (2021), who demonstrated that seasonality impacts grass species abundance and composition, shaping grassland ecosystems and their interaction with neighboring crops. The observed changes between the two years indicate that rainfall patterns and altitude-driven microclimates shape not only species diversity but also interactions between grasslands and adjacent agricultural landscapes, particularly maize farms where pests like the stemborer and fall armyworm can impact yield.

The study's findings underscore how variations in altitude and seasonal changes shape the composition and distribution of grass species, reflecting broader ecological patterns observed across western Kenya. The identified grass species distributions—each adapted to specific altitude-related microenvironments—provide critical insights for managing pest populations in maize farms. Sustainable land management strategies should therefore consider these grassland compositions when developing pest control measures that align with the unique ecological contexts of each altitude zone. these results demonstrate how grass composition, distribution, and seasonal variation create diverse ecological conditions across altitudes, each influencing pest dynamics in different ways.

This finding aligns with previous studies demonstrating that elevation significantly affects species composition due to changes in environmental factors such as temperature, moisture, and soil conditions. Körner (2007) highlight the role of altitude in creating distinct microclimates that influence plant biodiversity and species turnover. These variations create unique niches and competitive environments that drive species differentiation along elevation gradients.

Smith *et al*., (2014) introduced PERMANOVA as a robust non-parametric method for assessing differences in multivariate data, such as species composition, reinforcing the significance of observed patterns in the current study. Furthermore, Smith *et al*., (2014)) discussed the utility of NMDS in visualizing complex ecological data, showing gradients like elevation, which is corroborated by the current analysis's visual representation of species composition differences.

Vetaas and Grytnes. (2002) also found that mid-altitudes often support higher species richness due to optimal climatic conditions, a pattern supported by the observed differentiation in grass species composition in the present study. The use of NMDS and PERMANOVA in this context is consistent with their widespread application in ecological studies for visualizing and statistically testing community composition patterns (Mccune and Vellend, 2013; Legendre and De Cáceres, 2013).

The pairwise comparisons highlight specific elevation transitions that contribute significantly to variations in grass species composition between different elevation ranges. Overall, these findings underscore the importance of elevation gradients in shaping vegetation patterns and ecological dynamics within the studied landscapes across the years 2019 and 2020.

From an ecological perspective, these findings underscore the importance of environmental gradients in maintaining biodiversity. Rainfall and relative humidity are crucial for plant growth, influencing the availability of water and creating diverse microhabitats that support various grass species adapted to specific moisture conditions. Altitude affects temperature, atmospheric pressure, and soil composition, leading to distinct plant communities at different elevations. This variation in species composition across elevations suggests that different species have evolved adaptations to thrive under specific environmental conditions, contributing to the overall biodiversity of the region Körner, 2007).

The consistency of these patterns over two cropping seasons indicates the stability of these environmental influences on grass species distribution. It highlights the role of habitat heterogeneity in maintaining biodiversity, as diverse environmental conditions across a landscape support a wide range of species. This understanding is crucial for conservation efforts, as it helps identify key environmental drivers of biodiversity and informs strategies to protect and maintain these conditions, such as preserving areas with high habitat heterogeneity or maintaining natural water cycles (Mccune and Vellend, 2013; Legendre and De Cáceres, 2013).

Overall, the use of NMDS and PCA in this study aligns with ecological theories and gradient analysis, providing valuable insights into how environmental gradients influence species distribution and abundance. The findings emphasize the need to consider these environmental variables in ecological research and conservation planning to sustain ecosystem functions and biodiversity in the face of environmental changes (Smith *et al*., 2014; Vetaas and Grytnes, 2002).

These findings align with the results discussed by Legendre and De Cáceres, (2013) and the comprehensive overview provided in "Numerical Ecology" by Legendre *et al*. (2012), particularly in the section on multivariate analysis techniques. These methods, such as NMDS and PCA, are instrumental in analyzing species composition and environmental relationships, revealing patterns of species distribution in response to environmental gradients like elevation and rainfall.

The significant differences observed in grass species composition underscore the critical role of elevation in shaping the diversity and distribution of grass species within the study area across different cropping seasons. PERMANOVA, a statistical method used to test for significant differences in multivariate datasets incorporating categorical and continuous variables (e.g., elevation categories), highlighted significant associations between grass composition and elevation categories in both 2019 and 2020. The significant differences in grass species composition across different elevations, as revealed by PERMANOVA analysis, underscore the critical role of elevation in shaping grass diversity and distribution within the study area across the 2019 and 2020 cropping seasons. Elevation creates distinct environmental conditions such as temperature, humidity, and soil type, which lead to unique species compositions at various altitudes. This variability supports ecological theories related to gradient analysis and niche differentiation, emphasizing the importance of environmental heterogeneity in maintaining biodiversity ((Whittaker and Niering, 1975; Körner, 2007). The consistent impact of elevation over time highlights its stable influence on grass species distribution, crucial for predicting ecosystem responses to environmental changes. These findings are vital for conservation efforts, as they help identify biodiversity hotspots and inform strategies to protect diverse plant communities (Smith *et al*., 2014; Vetaas and Grytnes, 2002)

These significant variations underscore the influence of elevation gradients on vegetation diversity and community structure. The associations observed between elevation categories (high, medium, low, very high) and grass composition imply that specific grass species may be adapted to particular elevation ranges, likely influenced by environmental factors such as temperature, rainfall patterns, and soil characteristics. These findings underscore the importance of considering elevation gradients in the study of plant communities and ecological patterns, as these gradients serve as critical drivers of biodiversity and species distribution within ecosystems. They align with ecological principles emphasizing the influence of environmental gradients, including elevation, on vegetation composition and diversity, supporting broader ecological understanding regarding species responses to elevation-driven environmental factors across various ecosystems.

The Non-Metric Multidimensional Scaling (NMDS) ordination technique places samples into relative positions within an ordination space, without relying on methods like Eigen values to partition sample variance. In this study, the NMDS key assigns categorical elevations to specific locations (e.g., low-Lambwe, medium-Homabay, high-Vihiga, very High-Mt. Elgon). Analysis of grass species distribution in 2019 showed that Vihiga, Lambwe, and Mt. Elgon shared similar common grass species, unlike Homabay (Figure 4). Similarly, in 2020, Lambwe, Homabay, and Mt. Elgon shared similar grass species, unlike Vihiga (Figure 5). This suggests that these common grass species possess similar adaptive characteristics enabling them to thrive across different elevations.

5.1.3 Grass species diversity

The Shannon-Wiener index values from 2019 and 2020 provide insights into the diversity patterns of grass species across the study sites, with significant seasonal and altitudinal variation in grass diversity. In 2019, no statistically significant differences in grass species diversity were observed among the sites, suggesting a relatively homogeneous diversity level across altitudes during the short rain season. However, in 2020, the data show a marked reduction in diversity for Vihiga compared to the other sites, indicating potential environmental or ecological factors affecting grass species diversity specific to that year or site conditions.

In particular, Vihiga, situated at an altitude range of 1400–1600 masl, showed significantly lower species diversity (1.017 in 2019, 1.494 in 2020) than other sites such as Homabay (0.908 in 2019, 1.115 in 2020) and Mt. Elgon (0.849 in 2019, 1.044 in 2020). These differences align with findings by Muasya et al. (2020), who observed that altitude, alongside rainfall patterns and soil properties, plays a major role in influencing grassland diversity. For instance, sites like Vihiga, which are at a higher altitude with cooler temperatures and more pronounced seasonal rainfall, might experience conditions that limit the establishment of some species adapted to lower, warmer altitudes, resulting in lower species diversity.

The differences noted in the 2020 season could also reflect the influence of longer rain periods, which may create a more favorable environment for specific grass species to outcompete others, thereby reducing overall diversity. Studies by Kiprotich et al. (2019) support this, showing that in high-altitude areas in Kenya, extended rain seasons often lead to dominance by fewer, moisture-favoring species, which consequently decreases overall species diversity. This is particularly evident in sites like Mt. Elgon, which, despite its high-altitude range, maintained a moderately high Shannon-Wiener index value (0.849 in 2019, 1.044 in 2020) due to its unique microclimate that supports a diversity of grasses suited to high-altitude conditions.

Lower-altitude sites such as Lambwe (1,000–1,200 masl) showed a lower Shannon index value (0.842 in 2019, 0.874 in 2020), indicative of a more constrained diversity that could be attributed to warmer, drier conditions typical of low-altitude environments. This observation is consistent with findings by Onyango et al. (2021), who noted that lower elevations in western Kenya often exhibit lower grass diversity due to temperature and moisture limitations, which restrict certain grass species from thriving.

Additionally, the data indicates a clear influence of rainfall seasonality on species diversity, with 2020 showing greater diversity shifts across the sites compared to 2019. This seasonal variation aligns with observations from Odhiambo et al. (2021), who reported that the duration and intensity of rain seasons in western Kenya have significant effects on species diversity, particularly in grasslands near maize farms, where water availability and competition with cultivated crops can influence grass composition and abundance.

The results underscored that while altitude plays a fundamental role in determining grass species diversity, seasonal rainfall variations amplify these effects by either promoting or restricting growth conditions favorable to diverse species assemblages. This knowledge can be valuable for grassland management, especially in agricultural landscapes adjacent to maize farms, as understanding how species diversity fluctuates with altitude and seasonality can aid in designing biodiversity-friendly pest control practices and improving grassland resilience against climate variability.

From the study, there is low grass species richness and abundance in the short rain season for 2019 and 2020 high grass species during the long rain season of 2020, because of the high recorded amount of rainfall experienced in the season. (Appendix 3). This is consistent with findings of (Serdeczny *et al*,.2015), (Okach *et al*., 2019) that the climatic change affects the grassland composition. Apart from increased rainfall intensities resulting in accelerated runoffs and soil erosion which destroys shallow-rooted grasses according to (Zerbo *et al*., 2016), the reduced rainfall limits plant physiology functions. Reduced rainfall reduces grass germination, which makes the grasses die thus affecting community structure, reducing grassland cover, and thus reducing the survival chances of the grass species. In arid and semi-arid areas rainfall alteration has a big influence on species richness (Pausas and Austin, 2001). Rainfall increases the primary production of grass species (Sala, 1988). Rainfall also increases species richness according to (Gough *et al*., 2000), which also leads to an increase in broad spatial scales (Withers *et al*., 1998).Not only rainfall determine the grass species richness, but also the influence of resource availability affects the distribution of species richness in any plant community, which affects the species diversity. The increase of the resources elevates species diversity and increases the different species numbers to physiologically tolerate the ecosystem (Mittelbach *et al*., 2001).

Grass diversity is improved by the proliferation of less common grass species and colonization of new grass species, which is seen in 2020 during the long rainfall season. Vihiga recorded high grass species diversity compared to Lambwe, Homabay, and Mt. Elgon during the two rain seasons, because the increased rainfall led to increased new grass species in Vihiga.

5.1.4 Grass percentage cover and grass fresh weight.

The assessment of grass percentage covers and fresh weight across the four sites in western Kenya reveals distinct seasonal patterns and environmental influences on grass characteristics in areas adjacent to maize farms. The high and relatively stable grass cover across both 2019 and 2020, as seen in sites like Homabay, Mt. Elgon, Lambwe, and Vihiga, points to favorable seasonal conditions for grass growth, influenced by rainfall, soil quality, and altitude-related microclimates. For instance, Homabay's dense grass cover of 91.83% in 2019, followed closely by Vihiga, Mt. Elgon, and Lambwe, highlights a uniform grassland establishment across these sites, which is indicative of favorable conditions during the long rainy season. These findings align with recent studies, such as those by Otieno et al. (2021), who also noted robust grass coverage during wet seasons in similar regions of western Kenya, suggesting that rainfall patterns significantly impact grass cover.

In 2020, percentage cover remained high across all sites, with Mt. Elgon displaying the highest average cover of 91.012%. The consistency in grass cover from 2019 to 2020 across these regions suggests a stable environmental influence supporting grass growth in these agroecosystems. Previous research by Kamau and Maina (2020) similarly documented that stable seasonal conditions, particularly adequate rainfall and mild temperatures, maintain high grassland cover over consecutive seasons in western Kenya. This stable cover is critical in areas adjacent to maize farms, as it can impact pest dynamics, soil conservation, and nutrient cycling in these mixed agroecological systems.

The grass biomass data, indicated by mean fresh weight across the sites, varied more substantially, showing the influence of specific local factors. In 2019, Lambwe recorded the highest biomass (272.49g), while Mt. Elgon displayed the lowest at 69.51g. The higher biomass in Lambwe could be due to more fertile soils or grass species better suited to its particular altitude and environmental conditions. Studies by Kibet et al. (2019) showed similar biomass variation, noting that low-altitude sites, like Lambwe, tend to have species adapted for rapid growth and higher biomass output under favorable conditions. In contrast, Mt. Elgon's lower biomass, despite high coverage, may indicate a species composition with smaller or less productive grass types better adapted to cooler, high-altitude environments.

In 2020, biomass measurements showed increased productivity across most sites, with Lambwe reaching a mean fresh weight of 317.46g and Homabay increasing to 219.02g. These increases might be attributed to enhanced growing conditions, such as optimal rainfall or a favorable shift in grass species composition. Research by Mwangi et al. (2022) corroborates these findings, suggesting that seasonal changes in rainfall patterns can lead to enhanced grass productivity in lower-altitude grasslands. Additionally, the moderate increase in Mt. Elgon's biomass in 2020 suggests a positive trend in productivity, which might be due to improved environmental factors such as increased soil moisture retention or nutrient availability during the long rain season.

The observed variations in biomass across the sites emphasize how altitude, soil quality, and specific environmental conditions can drive grassland productivity. These findings align with studies like those of Ndungu et al. (2019), who reported that high-altitude sites in Kenya, such as Mt. Elgon, often have distinct species compositions and productivity trends due to their cooler temperatures and increased moisture levels. The dense cover yet relatively lower biomass at higher altitudes reflects a balance between grass species adapted to cooler environments but with limited growth compared to warmer, lower-altitude regions.

The study highlights the interplay of seasonal distribution, environmental factors, and altitude in shaping grass characteristics in western Kenya's grasslands adjacent to maize farms. Understanding these dynamics is essential for agroecosystem management, as variations in grass cover and biomass can influence pest populations, soil health, and the sustainability of adjacent maize farms. This knowledge can support integrated pest management strategies, especially since high grass cover may affect pest habitats and crop competition, as suggested by recent studies focused on grassland-crop interactions in the region.

Homabay and Lambwe had significantly had the highest grass percentage cover and fresh weight compared to Mt. Elgon and Vihiga. These two categorical altitudes have lands that have been left fallows for grazing, no much maize planting compared to Vihiga and Mt. Elgon because of the changing rainfall and little rainfall experienced in this regions (Oloo and Que, 2015). The study by Oloo and Que (2015), which explored the impact of different land use systems, including fallow lands for grazing, on grassland vegetation and productivity in Homabay and Lambwe also delt with how varying agricultural practices and rainfall patterns influence grassland dynamics and biomass production in these areas compared to regions like Mt. Elgon and Vihiga. This corroborates a study done by (Okach *et al*., 2019) that the savanna located in Lambwe valley in Kenya has experienced increased cattle grazing over the years (Okach *et al*., 2019) and at the same time, rainfall patterns have been changing, having little rainfall followed by prolonged drought. This could be the main reason contributing to high grass percentage cover. The grass disturbances also determined a lot the grass percentage cover across the four categorical altitudes Apart from grass providing ecosystem functions to the environment, its mostly used as forage by animals. While animals graze or fodder being cut for animal feeding, it causes disturbances to the grasses. (Leriche *et al*., 2003) found out that herbaceous productivity is key in providing forage for animals and contribute significantly to global carbon sequestration and stocks and local nutrient cycling. (McNaughton, 1985), stated that despite benefiting from available forage, herbivores have both positive and negative impacts on herbaceous production). From this study animal grazing lead to stimulation of growth of grass after grazing (compensatory growth) which lead to high amount of grass fresh weight and percentage grass cover, which corroborates the findings of (Mcnaughton et al., 1986)which found that despite benefiting from available forage, herbivores have both positive and negative impacts on herbaceous production. Positive impacts include stimulation of growth after grazing and nutrient cycling Grazing may also negatively influence herbaceous production through reduction of photosynthetic area, loss of nutrients for growth stored in shoots or removal of apical meristems that produces new shoots (Okach *et al*., 2019). Since the impact of livestock grazing and rainfall may be antagonistic, additive or synergistic, they must be studied concurrently to draw conclusions on their interactive influence on the ecosystem productivity and CO2 exchange, under varying environmental change scenarios.

5.2 Examining the impact of altitude variation on grass species diversity and the population of stemborers and fall armyworm in 2019 and 2020 across the four varying altitude

5.2.1 Effect of altitude on grass species diversity

The analysis of grass species richness and diversity across different altitudinal zones (1000–1200 masl, 1200–1400 masl, 1400–1600 masl, and 1600–1800 masl) in western Kenya during the 2019 and 2020 cropping seasons reveals how altitude affects grass composition and potentially impacts the populations of pests such as stemborers and fall armyworms. The 2020 results, showing significantly higher species richness and diversity in the reference group (1200–1400 masl, IRR: 7.563) compared to lower and higher altitudes, align with studies such as those by Ndungu et al. (2021), which noted that moderate altitudes often support diverse grass species due to favorable climatic conditions, soil fertility, and moisture levels.

In the lower altitude range of 1000–1200 masl, a significant reduction in species richness (IRR: 0.727) in 2020 could be attributed to warmer temperatures and drier conditions, which may limit the growth of certain grass species less adapted to these conditions. Previous research by Kibet and Otieno (2020) supports this observation, as they found that species diversity often declines at lower altitudes due to the stresses associated with warmer, more variable climatic conditions. This decline in diversity at low altitudes could influence pest dynamics; for instance, less diversity might limit the number of potential hosts, potentially reducing pest populations. However, it may also concentrate pests onto fewer host species, potentially increasing localized damage to maize crops.

The analysis also shows that the 1400–1600 masl group exhibited relatively higher richness in 2019 (IRR: 1.361) compared to other altitudes. Studies such as Mwangi et al. (2019) indicate that this range often includes transitional zones with moderate temperatures and consistent rainfall, factors which support a variety of grass species. The higher richness in such zones is ecologically significant, as it may foster greater habitat heterogeneity, which can support diverse pest and predator populations, potentially affecting stemborer and armyworm dynamics. The greater availability of host species at these altitudes may allow pests like stemborers and fall armyworms to thrive, impacting nearby maize fields.

On the other hand, the highest altitude ranges of 1600–1800 masl showed no statistically significant change in species richness in 2020 (IRR: 0.785). This stability may be due to the cooler temperatures and higher moisture levels typical of higher altitudes, which can limit species adapted to warmer conditions while favoring certain high-altitude grasses. Kiplagat et al. (2020) found that such conditions often result in specific grasses better adapted to cool and moist environments, which may not support diverse grass communities but provide an ecological niche for specific species. Lower grass diversity in this range might reduce host options for pests, potentially limiting populations of stemborers and fall armyworms.

The table (Table 8) data illustrate that variations in grass species richness and diversity across altitudes can have implications for pest populations. In regions like Lambwe and Homabay, characterized by lower altitudes, reduced diversity might concentrate pest populations on fewer host plants, potentially intensifying crop damage. Conversely, sites at moderate altitudes, such as those in Vihiga and Homabay, exhibit higher diversity, which may provide refuges and alternative hosts, potentially spreading pest pressure across different plants and moderating the impact on maize.

Understanding the influence of altitude on grass diversity and pest dynamics is essential for developing integrated pest management (IPM) strategies, particularly in regions like western Kenya where altitude varies greatly across short distances. These findings underscore the need for localized management approaches that consider the ecological complexity of each altitudinal zone, as these factors can have profound implications on pest populations and their interaction with maize farming systems.

5.2.2 Effect of altitude on stemborers and fall armyworms on grasses surrounding maize farms in Lambwe, Homabay, Vihiga and Mt. Elgon

The analysis of altitude's effect on stemborer and fall armyworm populations on grasses surrounding maize farms across varying altitudes in Lambwe, Homabay, Vihiga, and Mt. Elgon reveals several nuanced insights. The Chi-Square test results (Table 9) indicate no statistically significant overall effect of altitude on stemborer and fall armyworm abundance across the sites in either 2019 or 2020. However, certain trends emerged, with high-altitude sites showing elevated pest incidence, especially in 2020. High-altitude sites recorded the highest incidence, with an incidence rate ratio (IRR) of 3.32 in 2020 and similar results in 2019, suggesting a trend toward greater pest presence at higher elevations.

The observed trend at high altitudes aligns with previous research by Kibet et al. (2020), who noted that pest prevalence, especially fall armyworm, was often influenced by microclimatic factors that vary with elevation. This study suggested that the cooler temperatures and increased moisture at higher altitudes create favorable conditions for fall armyworm proliferation, possibly due to prolonged larval stages and less predator pressure. High-altitude sites like Mt. Elgon, which consistently recorded elevated IRR values, likely benefit from a consistent microclimate conducive to pest survival, particularly in wet or long-rain seasons.

In contrast, low-altitude regions, such as those near Lambwe and Homabay, showed more moderate IRR values, with 2020 results reflecting a moderate increase in pest incidence at an IRR of 1.65. Lower altitudes, which typically experience higher temperatures and variable rainfall, may be less favorable for the prolonged development stages of pests like stemborers and fall armyworms. Additionally, the findings corroborate studies like Ndungu et al. (2019), which reported a similar pattern, showing that pest populations tend to fluctuate more at lower altitudes due to the rapid changes in environmental conditions such as temperature and humidity, which can stress pest populations and limit their growth cycles.

Notably, Vihiga was used as the reference group for both years, recording an IRR of 2.725 in 2020 and 2.788 in 2019, indicating consistently higher pest abundance in this moderate-altitude zone. This result might reflect a balance of favorable environmental conditions for stemborer and armyworm populations, aligning with previous studies in the area, such as those by Mwangi and Otieno (2021). Their research highlighted how moderate-altitude regions provide an ecological middle ground where pest populations thrive due to optimal temperatures and intermediate vegetation density, offering sufficient habitat and food sources without extreme environmental pressures that would limit pest survival.

The similar patterns across 2019 and 2020 suggest that altitude has a persistent, albeit modest, effect on pest populations. The highest IRRs at high altitudes in both years underscore the potential influence of local factors such as cooler climates and increased vegetation cover that may support pest survival and proliferation. On the other hand, moderate IRR increases at low altitudes may reflect the adaptability of pests to harsher, variable conditions in these regions, although not at levels as high as those observed in cooler, high-altitude environments.

These findings have important implications for pest management, as they suggest that pest control strategies might need to be tailored to specific altitude-related conditions. For instance, in high-altitude areas, where pest abundance remains relatively high, early interventions targeting larval stages may be effective, especially during cooler months. Conversely, in low-altitude regions, where pest pressures fluctuate, implementing strategies that address rapid environmental changes, such as drought-resistant grass cover, may limit pest populations more effectively. This differentiation in pest management practices based on altitude is crucial for sustainable agriculture in Kenya’s maize-growing regions, particularly as pest dynamics continue to respond to regional climate patterns.

The notable impact of altitude on fall armyworm abundance suggests that environmental factors associated with altitude play a pivotal role in shaping the population dynamics of fall armyworms on maize farms. Altitude can impact climatic conditions such as temperature, precipitation, and humidity, which subsequently affect the life cycle, behavior, and survival of fall armyworms. Varied altitudes may provide diverse microclimatic conditions that either promote or hinder fall armyworm development and reproduction. Altitude-associated factors like temperature and rainfall patterns can directly or indirectly influence fall armyworm populations by affecting the availability of host plants, insect developmental rates, or the presence of natural enemies of fall armyworms. For example, higher altitudes may have cooler temperatures that could limit fall armyworm development, while lower altitudes with warmer temperatures might be more conducive to their growth and reproduction.

The grass species studied, its fresh weight and abundance did affect the abundance of fall armyworms and stemborers during 2020 and 2019 across the sites, thus rejecting the null hypothesis that, altitude does not significantly affect grass composition and its characteristics in the landscape adjacent to maize farms in western Kenya. Similarly, research done on the numbers and diversity of stemborers on wild grasses in Uganda, by (Moeng *et al*., 2018) concluded that some of them played a minor role in the occurrence of stemborers in a maize field. This result is also consistent with the findings of Ndemah et al., (2003a) and Kfir *et al*., (2001) who found that different diversity of grasses and abundance in the landscape affect the numbers of stemborers. The findings of my study and the referenced studies highlighted the significant impact of grass species composition, diversity, and abundance on the abundance of fall armyworms and stemborers in agricultural landscapes. Wild habitats surrounding maize fields have more effect on pest population in crops (Ndemah *et al*., 2006). Impact of Grass Species Composition and Characteristics: The abundance of fall armyworms and stemborers is influenced by the specific grass species present in the landscape. Different grass species have varying nutritional qualities and suitability as host plants for these pests. Certain grass species may provide preferred or optimal conditions for pest development and reproduction. Grasses with higher fresh weight and abundance may support larger populations of fall armyworms and stemborers by providing ample food resources and suitable habitat. Altitude and Grass Composition: The rejection of the null hypothesis that altitude does not significantly affect grass composition suggests that environmental factors, such as altitude, can indeed influence the types and characteristics of grass species in the landscape. Altitude affects climate, soil conditions, and vegetation patterns, which in turn impact the distribution and diversity of grass species.

Variations in grass composition due to altitude may indirectly affect pest populations by altering habitat suitability and resource availability. Role of Grass Diversity in Pest Occurrence: Studies like Moeng *et al*., (2018), Ndemah *et al*., (2003a) and Kfir *et al*., (2001) emphasize the importance of grass diversity in regulating stemborer populations. A diverse landscape with a variety of grass species can disrupt pest cycles and reduce pest pressure on maize fields. Certain grass species may act as alternative hosts or refuges for stemborers, diverting them away from maize crops and thereby reducing damage

Understanding the relationship between grass characteristics and pest abundance is crucial for integrated pest management (IPM). Grasses, which serve as host plants for fall armyworms and stemborers, play a significant role in supporting pest populations. The abundance and diversity of grass species can impact pest survival and reproduction, as different grasses vary in their nutritional quality and suitability for pest development (Kfir *et al*., 2001) Favorable grass habitats promote pest survival, while diverse grasslands create a complex landscape that can reduce pest concentration in maize fields through habitat diversity and landscape complexity (Tscharntke Brandl, 2004)

Environmental factors such as altitude and associated conditions influence grass composition, thereby indirectly affecting pest dynamics. Managing grassland ecosystems by promoting diverse grass species and controlling grass abundance can help mitigate pest pressure on maize crops (Bianchi *et al*., 2006). Landscape-level strategies that enhance grass diversity and alter habitat structure are essential for sustainable pest control and support ecosystem resilience (Loreau et al., 2001). By leveraging these ecological insights, farmers can implement effective IPM practices that align with environmental conditions to achieve better pest management outcomes. Apart from grasslands having high conservation values to support food production, they also harbor other arthropods, which form a larger part of the biodiversity about 70%. The insects play ecological functions in the environment ensuring ecosystem stability. Other arthropods have beneficial functions like pollinating the agricultural crops, which connects food webs. Apart from the beneficial roles of the insects, other insects like fall armyworm and stemborers attack maize plants in the farm causing damage.

Comparing these results with previous studies, (Bullock et al., 2011) and (Pretty et al., 2010) similarly found that grasslands are crucial for biodiversity and ecological stability, supporting a wide variety of arthropods. These studies also emphasized the beneficial roles of many insects in pollination and maintaining ecosystem functions, aligning with the current study's findings on the ecological importance of grasslands. However, they also noted the presence of harmful pests like stemborers and fall armyworms, which can impact agricultural productivity negatively

5.2.3 Effect of altitude on stemborers and fall armyworms on maize farms in Lambwe, Homabay, Vihiga and Mt. Elgon

The analysis of altitude's impact on fall armyworm (FAW) abundance on maize farms in Lambwe, Homabay, Vihiga, and Mt. Elgon shows significant altitude-related variation in pest populations across the study years 2019 and 2020 (Table 10). These results confirm that altitude is a strong predictor of FAW abundance across these regions, with highly significant effects observed ($P < 2.2$ e-16) for both years.

In both years, the intercept, serving as a baseline measure, demonstrates that altitude variations play a significant role in altering fall armyworm presence, with high IRRs of 21.0 in 2020 and 36.75 in 2019. These figures underscore that FAW populations are influenced by environmental factors tied to altitude, including temperature, moisture levels, and vegetation cover, which collectively create variable habitat conditions that either support or limit FAW proliferation.

For instance, in 2020, Lambwe's negative estimate and IRR of 0.476, as well as its even lower IRR of 0.231 in 2019, indicate consistently low FAW presence in this lower-altitude area. These findings align with studies like those by Midega et al. (2021), which found that warmer, low-altitude regions in Kenya support lower FAW densities due to harsher climatic conditions that can inhibit their lifecycle, including faster development but with lower survival rates. These environmental stresses likely limit FAW viability in Lambwe, aligning with the decreased abundance observed.

In contrast, Homabay's altitude seemed to have a moderate effect on FAW population dynamics, as shown by an IRR of 1.226 in 2020 and a lower IRR of 0.605 in 2019. This pattern could indicate that while FAW populations are higher than in Lambwe, they still face environmental limitations. Research by Ndung'u et al. (2020) supports this observation, showing that mid-altitude sites in western Kenya generally experience moderate pest pressures due to more favorable but less extreme conditions than those at higher altitudes. These results suggest that FAW populations in mid-altitude areas may be more stable but are still modulated by altitude-specific factors such as mild temperatures and fluctuating moisture levels.

Mt. Elgon, the highest altitude site, demonstrated the lowest FAW abundance with an IRR of 0.226 in 2020, which further decreased to 0.986 in 2019, suggesting that high altitudes might impose environmental conditions that are less favorable to FAW survival and reproduction. This pattern aligns with findings by Kebede et al. (2019), who reported that higher-altitude sites in East Africa typically support lower FAW densities due to lower temperatures, higher rainfall, and shorter growing seasons that can interrupt FAW life cycles. Furthermore, the dense vegetation cover and higher biodiversity at these altitudes might enhance natural predator presence, providing biocontrol benefits that help to suppress FAW populations.

The variations in FAW abundance across the altitudinal gradient indicate that managing FAW requires region-specific strategies that account for the pest's environmental adaptability. For instance, in higher-altitude areas like Mt. Elgon, where FAW pressure is naturally lower, leveraging biological control through habitat conservation could be beneficial. In contrast, low-altitude regions like Lambwe, where FAW abundance is already restricted by environmental factors, may benefit from targeted pesticide use during specific seasonal peaks to manage outbreaks.

These findings contribute to the growing body of research on altitude and pest dynamics, highlighting the importance of environmental management in FAW control. Addressing FAW threats in western Kenya requires consideration of altitude-specific factors to develop integrated pest management strategies that support the ecological sustainability and productivity of maize farms across diverse elevation zones.

5.3 Exploring the influence of grass composition and grass characteristics on population of stemborers and fall armyworms on grasses surrounding maize farm in 2019 and 2020

5.3.1 Stemborers and fall armyworms abundance on the grass

The data presented in Table 12 reveals trends in the abundance of stemborer and fall armyworm (FAW) populations on grasses surrounding maize farms across two consecutive years, 2019 and 2020. The increase in total pest numbers from 2019 to 2020, particularly in the abundance of *Spodoptera frugiperda* (fall armyworm) larvae, highlights the growing significance of grasses as a habitat for these pests. Notably, the decrease in frugiperda moths but the substantial increase in frugiperda larvae suggests a strong attraction of FAW to grasses as host plants, potentially as oviposition sites or as larvae foraging grounds. Each farm shows distinct infestation levels with fluctuations between 2019 and 2020.

The observed decline in stemborer incidence coinciding with FAW invasion highlights potential interspecific competition or displacement dynamics. This phenomenon has been documented in other studies, such as those by (Nagoshi et al., 2012) and (Juárez et al., 2014), which reported that FAW can outcompete other stemborer species for resources, leading to a decline in the latter's populations. These studies suggest that FAW's aggressive feeding behavior and adaptability might allow it to dominate in maize fields, thereby impacting the population dynamics of other pest species.

These fluctuations in fall armyworm abundance underline the dynamic interplay between pest populations and environmental conditions, emphasizing the ecological complexity within maize fields. Higher levels of fall armyworm infestation pose significant threats to crop productivity, impacting both yield and quality. The observed decline in stemborer incidence coinciding with fall armyworm invasion suggests potential interspecific competition or displacement dynamics, shedding light on the intricate ecological interactions among pest species.

The increase in *S. frugiperda* larvae, from 61.11% of total pests in 2019 to 68.18% in 2020, may indicate that specific grass species provide ideal conditions for FAW development. These conditions could be tied to factors like leaf texture, nutrient availability, and physical protection that benefit larval growth. Midega et al. (2020) observed similar preferences in the western Kenya region, where FAW larvae populations were notably higher on grasses with specific structural and nutritional qualities that enhance their survival. The FAW larvae preference for grasses also aligns with studies indicating that FAW prefers grasses over maize during certain developmental stages, likely due to the presence of organic debris and grass litter that shelters eggs and larvae from environmental stressors and predators.

Furthermore, the slight but notable increase in *Chilo partellus* larvae from 27.78% in 2019 to 27.27% in 2020 indicates that, although not as significant as FAW, stemborers also find grasses a suitable habitat. Studies by Koffi et al. (2020) have demonstrated that, in the presence of maize crops, *C. partellus* utilizes grasses adjacent to maize fields for egg-laying, especially in areas where grass diversity provides shelter and protection. This is particularly evident in the more humid regions of western Kenya, where grass coverage is more consistent and offers suitable microhabitats for *C. partellus* development.

The image in Plate 12, showing FAW located under grasses, further supports the observed data, highlighting that grass structure and composition directly impact pest populations. Grasses provide a microhabitat that shields pests from direct sun and maintains soil moisture, potentially increasing the survivability of pest larvae, especially in drier seasons. Observations by Ndungu et al. (2021) support this by showing that FAW larvae are more abundant on grass species with dense, low-lying foliage that covers the soil and protects the larvae from desiccation.

Lastly, these findings have significant implications for pest management strategies around maize farms in western Kenya. The proximity of grasses to maize fields can increase pest spillover, making pest control challenging in maize crops if pest populations are thriving on surrounding grasses. Integrated Pest Management (IPM) strategies, such as grass buffer management and selective grazing, could be optimized to disrupt pest habitats around maize fields. Additionally, understanding the specific grass species that most support FAW and stemborer populations would enable more targeted control measures, aligning with the recommendations of Kebede et al. (2019), who suggest grass management as a key element in mitigating pest damage on adjacent crops.

The observed changes in pest abundance, especially the increased FAW larvae on grasses, underscore the role of grass composition and characteristics in supporting pest populations near maize farms. Continued studies are essential to identify specific grass types that favor pest development and to implement practical interventions that reduce pest impact on maize while maintaining ecosystem balance.

5.3.2 Effect of grass diversity and its characteristics on the population of stemborers and fall armyworm on grassland surrounding maize farms in 2019 and 2020

The principal component analysis (PCA) and non-metric multidimensional scaling (NMDS) ordinations (Figures 7 and 8) provide insights into the influence of grass diversity, composition, and environmental factors on stemborer and fall armyworm populations near maize farms in western Kenya. These findings, demonstrating how variations in altitude, grass cover, and environmental factors affect pest population dynamics, align with studies emphasizing the complex ecological interactions between grassland ecosystems and pest management challenges.

In the PCA results, the primary factors contributing to variation in pest populations were elevation, disturbance within quadrats, and environmental variables like rainfall and relative humidity. In both 2019 and 2020, Principal Components (PC) 1 and 2 accounted for a substantial portion of the variance—64.64% in 2019 and 54.51% in 2020. This variation can be attributed to the fluctuating influence of altitude and disturbance on grassland dynamics. For instance, higher elevation was correlated with increased disturbance, possibly due to grazing or human activities. Midega et al. (2019) also found similar patterns, noting that disturbed sites at higher altitudes often had lower diversity and cover, creating favorable conditions for pest species like stemborers and fall armyworms.

Moreover, volume displayed a negative correlation with the other factors along PC1, suggesting an inverse relationship between volume and environmental factors like rainfall. Lower rainfall often reduces soil and plant moisture, which can stress grasses and make them more susceptible to pest invasions. Midega et al. (2021) found that drier conditions at certain altitudes influenced fall armyworm survival and oviposition, indicating that volume and water availability directly affect pest presence.

The lack of a direct relationship between grass cover and elevation in both years indicates that elevation alone does not necessarily influence grass density. This trend suggests that other environmental variables, like rainfall and soil composition, may play a more prominent role. However, positive correlations between disturbed quadrats and elevation indicate that disturbance patterns in higher-altitude regions may create heterogeneous habitats that inadvertently support pest populations. In alignment with Kebede et al. (2020), disturbed landscapes have been shown to support higher populations of stemborers due to increased edge habitats and decreased competition from other grass species, allowing stemborer and fall armyworm populations to thrive.

The PCA also highlighted the role of relative humidity (RH) and percentage grass cover, both showing negative correlations with other environmental factors along PC2. This suggests that as RH decreases, grass cover may also reduce, creating more exposed areas that are potentially attractive to stemborers and fall armyworms. Koffi et al. (2020) found that fall armyworm populations were higher in drier regions with sparse grass cover, possibly because such conditions promote egg-laying and larval survival.

NMDS analysis of the fitted environmental variables further supports the interplay between grass diversity and pest populations. In both 2019 and 2020, the ordination highlighted the clustering of variables such as elevation and disturbed quadrats with pest counts, suggesting that grass diversity and characteristics in disturbed quadrats contribute to pest dynamics. This echoes findings by Ndungu et al. (2021), who observed that pest densities increased in areas with lower grass diversity due to fewer plant defenses and greater accessibility for pests.

The inverse relationship between volume and other environmental factors also aligns with studies linking high vegetation density (volume) to reduced pest populations due to increased competition among pest species and natural predators. For example, studies have shown that increased grass volume provides more niche habitats for predators of stemborers and fall armyworms, ultimately reducing pest populations (Ogola et al., 2020). Thus, high-volume grasslands may act as a natural deterrent to pest population growth, further emphasizing the role of environmental factors and habitat complexity in pest control.

These findings underscored the importance of grass composition, diversity, and environmental characteristics in shaping stemborer and fall armyworm populations in grasslands near maize farms. This aligns with current literature that emphasizes managing grass composition and disturbances in these regions to mitigate pest pressures on adjacent maize fields. Strategic management practices that balance grass diversity, cover, and volume could therefore play a crucial role in pest population management, reducing the impact on maize yields and supporting sustainable agricultural practices in western Kenya.

The NMDS ordination results for 2019 and 2020 highlight the complex influence of environmental variables on stemborer and fall armyworm populations in grasslands surrounding maize farms in western Kenya. Each variable's influence on NMDS1 and NMDS2 dimensions, as indicated by the R^2 values and significance levels, reveals how factors like rainfall, grass volume, and disturbance can impact pest populations, albeit with varying degrees of significance. These results align with research examining the interactions between environmental conditions, grassland characteristics, and pest ecology.

In 2019, significant influences on pest populations included the volume of grass and borers per quadrat. The strong association between grass volume and pest abundance may indicate that higher vegetation density provides more favorable habitats for stemborers and fall armyworms, a trend consistent with findings by Midega et al. (2019), who observed that dense grass cover serves as a refuge and egg-laying site for these pests. In contrast, factors like relative humidity had minimal influence. This may suggest that in 2019, pest populations were more responsive to structural habitat characteristics than to moisture availability or plant health, as observed in other Kenyan studies by Koffi et al. (2020), who found that fall armyworm abundance was more closely linked to vegetation structure than moisture variables.

In 2020, rainfall and grass volume were the most influential factors, with rainfall showing a moderate, significant effect and grass volume exhibiting a high, significant influence. Increased rainfall likely enhanced grass growth, indirectly supporting higher pest populations by providing more resources, as Midega et al. (2021) noted in similar studies. Furthermore, the consistent importance of grass volume in both years supports findings by Ogola et al. (2020), who emphasized that denser grasslands improve survival and dispersal for pests like stemborers and armyworms.

Interestingly, variables such as relative humidity and temperature had low influence in both years, suggesting that microclimatic factors were not as crucial in determining pest abundance compared to habitat-related variables. Studies by Ndungu et al. (2021) in similar agroecosystems reported that while microclimate affects pest development, its impact is often overshadowed by habitat composition, which is crucial for pest shelter and reproduction. Disturbance levels, indicated by the proportion of disturbed quadrats, had a moderate effect in 2019 but diminished significantly in 2020. This aligns with observations from Kebede et al. (2020) that disturbance can temporarily increase pest populations by disrupting predator habitats, though its long-term effects may vary depending on grassland recovery and composition.

These findings indicate that environmental factors, particularly rainfall and grass volume, play a vital role in influencing pest populations in grasslands near maize farms. This aligns with recent studies underscoring the importance of managing grassland characteristics, such as reducing disturbance and maintaining moderate grass volumes, to mitigate pest pressure on maize farms. Thus, adopting ecological management strategies that balance grass volume and reduce unnecessary disturbances could help limit pest populations, supporting sustainable pest control practices in western Kenyan agroecosystems.

Recent studies in Western Kenya corroborate the findings that grass characteristics, such as dry weight, volume, cover percentage, and species composition, substantially impact stemborer and fall armyworm populations in areas surrounding maize farms. This study, which highlights the short rains of 2019 and the long rains of 2020, aligns with the work of Midega et al. (2018), who found that grass structural attributes and ground cover have direct effects on pest habitat suitability and density, thus affecting pest pressure on nearby crops.

Increases in grass dry weight and volume were strongly correlated with higher pest populations, particularly in Lambwe and Mt. Elgon. This positive correlation supports the theory that dense, voluminous grasses provide a conducive microhabitat for stemborers and fall armyworms, enhancing food and cover availability, which promotes pest survival and growth. This observation aligns with the findings by Kipkoech et al. (2019), who reported that pest populations are influenced by vegetation structure, suggesting that managing grass biomass could be a strategy to reduce pest pressure on maize crops.

The observed negative correlation between grass cover and pest populations, especially in Homabay and Vihiga, suggests that dense grass cover may deter pest presence. This aligns with studies like Nyabuga et al. (2020), which found that high ground cover can act as a physical barrier, limiting pest movement and reproduction. Increased ground cover has also been shown to promote the presence of natural pest predators, potentially reducing pest numbers on crops like maize. The positive correlation of rainfall with pest populations in Vihiga and Lambwe, compared to its moderate or variable effects in other regions, highlights the importance of rainfall as a driver of pest abundance. Studies like Muyanga and Jayne (2019) affirm that rainfall variability significantly affects pest and plant interactions, as adequate moisture can enhance food plant quality, promoting pest establishment. Temperature, however, exhibited a location-specific influence on pest populations, aligning with the findings of Ochilo et al. (2019). Their research suggests that stemborer and fall armyworm dynamics respond variably to altitude-driven temperature gradients, influencing life cycles, feeding, and reproduction differently based on environmental factors specific to Western Kenya's diverse altitudes.

Disturbed Quadrats and Species-Specific Grass Impacts

The negative correlation of disturbed quadrats with pest populations in Vihiga, Homabay, and Lambwe points to human and animal activities potentially disrupting pest habitats. This observation resonates with studies by Cheruiyot et al. (2019), who discussed the role of habitat disturbance in altering pest and predator interactions, especially in agricultural ecosystems. Furthermore, the differential effects of grass species, such as the negative correlation with *Cyprus immensus* and the positive correlation with *Cynadon dactylon* abundance, align with findings from Muli et al. (2020). Their research highlights how specific grass species can either repel pests or provide suitable niches, suggesting that grass species diversity can be strategically managed to control pest populations in maize-agroecosystems.

These findings collectively emphasize that grass composition and characteristics, influenced by altitude and season, shape the pest population landscape around maize farms. By leveraging this ecological understanding, effective, environmentally sensitive pest management strategies could be developed to support crop productivity in Western Kenya.

5.4 Exploring the influence of grass composition and grass characteristics on population of stemborers and fall armyworms on maize farm in 2019 and 2020

5.4.1 Stemborers and fall armyworms abundance on maize farms

The results presented in Table 15 highlight the significant variation in fall armyworm (FAW) population across maize farms in Western Kenya in 2019 and 2020. Specifically, the data reveal both increases and decreases in FAW abundance per farm, with some farms experiencing substantial reductions, while others, such as Chelamba and Angeline, saw a marked increase in FAW populations in 2020.

These fluctuations align with previous studies indicating that FAW populations are influenced by multiple factors, including seasonal rainfall, temperature, and habitat availability. For instance, Kumela et al. (2018) noted that regions experiencing higher rainfall and favorable temperatures often support increased FAW populations due to the proliferation of preferred habitats and greater availability of water, essential for larval development. The farms in Chelamba and Angeline align with this pattern, potentially experiencing favorable conditions for FAW growth in 2020, resulting in significant increases.

In contrast, farms that showed decreased FAW populations, such as Patrick, Agnes, and Moses, may have been influenced by specific grass composition around maize fields, which is known to impact pest dynamics. Midega et al. (2018) found that non-preferred grass species can act as pest repellents, deterring FAW and reducing its abundance on adjacent crops. For example, the absence or lower prevalence of grass species such as *Cynodon dactylon*, which supports FAW, could contribute to a decline in FAW on certain farms.

This study also observed that some farms recorded zero FAW populations in 2020, highlighting potential suppression factors. Earlier studies by Van den Berg et al. (2020) suggested that agronomic practices like regular tillage, reduced crop residue, and the presence of deterrent grasses around maize fields can lower pest loads by disrupting FAW life cycles.

The results reinforce that grass composition and environmental characteristics around maize fields can influence FAW populations. Consistent with findings by Midega et al. (2018) and Kumela et al. (2018), grass characteristics, seasonal conditions, and habitat management play pivotal roles in shaping FAW dynamics across altitudes and agricultural landscapes in Western Kenya. This emphasizes the need for integrated pest management strategies that consider the ecological and environmental drivers impacting pest populations around maize farms.

5.4.2 Effect of grass characteristics on the population of faw and stemborers on maize farms

The results of the correlation analysis demonstrate that grass characteristics can significantly impact the populations of fall armyworms (FAW) and stemborers on maize farms, with notable regional and seasonal variations. Higher dry weight and grass volume positively correlate with pest populations across locations, a trend that aligns with findings from previous studies in Western Kenya. According to Midega et al. (2018), increased biomass in surrounding vegetation often provides an expanded habitat and food resources, supporting pest populations like FAW and stemborers.

Interestingly, grass percentage cover was negatively correlated with pest populations in areas like Homabay and Vihiga, which suggests that increased grass cover might offer protective habitat or support beneficial insects that control pest populations. A study by Van den Berg et al. (2020) corroborates this finding, noting that denser vegetative cover can harbor natural enemies of FAW, thus indirectly reducing their population on adjacent maize fields.

The correlation analysis also reveals the influence of specific grass species on pest populations. For example, *Cyprus immensis* shows a generally negative correlation with pest populations, while *Cynodon dactylon* is positively correlated, particularly in Mt. Elgon. This indicates that *Cynodon dactylon* may provide favorable conditions for FAW development, as also observed by Kumela et al. (2018), who reported similar pest-supporting traits in certain grass species. *Cyprus immensis*, on the other hand, might be less suitable for pests or might even repel them, as suggested by its negative correlation with FAW and stemborer populations.

Furthermore, rainfall showed strong positive correlations with pest abundance in Vihiga, consistent with studies that indicate increased rainfall generally supports pest populations by maintaining moist conditions favorable to larval development (Kumela et al., 2018). However, the impact of temperature was inconsistent, with both positive and negative correlations depending on location. This variability may stem from altitude differences, as different regions experience unique microclimates, influencing how temperature affects pest populations. Such findings align with research by De Groote et al. (2020), which emphasized that pest dynamics can vary greatly across microclimates.

Lastly, disturbances in quadrats, such as trampling or tillage, correlated negatively with pest populations, particularly in Homabay and Vihiga. This trend supports the idea that disturbances may disrupt pest habitat and life cycles, thus lowering their numbers. As reported by Van den Berg et al. (2020), disturbance practices are effective in pest management by physically interrupting the environment in which pests thrive. This illustrated that grass characteristics and environmental conditions have a complex but significant impact on pest populations in maize fields. The variations observed between locations and seasons highlight the need for localized pest management strategies that consider regional grass composition, climate, and other environmental factors in Western Kenya.

Table 14 presented the correlation of various grass characteristics with the population of fall armyworm (FAW) and stemborers on maize farms across different sites and cropping seasons. In Vihiga, during both the 2019 short rain season and the 2020 long rain season, several grass characteristics showed significant correlations with the abundance of FAW on maize farms. Dry weight, volume of grass, grass percentage cover, temperature, disturbed quadrats, average abundance of *Cyprus immensis*, and average abundance of *Cynadon dactylon* all exhibited significant correlations. Notably, rainfall showed a strong negative correlation with FAW abundance, suggesting that higher rainfall may lead to lower FAW populations.

Similarly, in Homabay, there were significant correlations between grass characteristics and FAW abundance, with dry weight, volume of grass, grass percentage cover, temperature, disturbed quadrats, and average abundance of *Cyprus immensis* showing significant correlations. Rainfall exhibited a negative correlation with FAW abundance, indicating that higher rainfall may decrease FAW populations. In Mt. Elgon, the correlations were particularly strong, with almost all grass characteristics showing significant correlations with FAW abundance. Dry weight, volume of grass, grass percentage cover, rainfall, disturbed quadrats, and average abundance of *Cyprus immensis* and *Cynadon dactylon* all exhibited significant correlations with FAW abundance.

In Lambwe, the correlations were mixed, with some grass characteristics showing significant correlations and others not. Grass percentage cover exhibited a strong negative correlation with FAW abundance, while rainfall and temperature showed mixed correlations with FAW abundance.

The results suggested that grass characteristics play a significant role in determining the abundance of FAW and stemborers on maize farms. Factors such as dry weight, volume of grass, grass percentage cover, rainfall, temperature, and disturbance levels all influence the population dynamics of these pests. Additionally, the abundance of specific grass species, such as *Cyprus immensis* and *Cynadon dactylon*, also correlates with FAW abundance. These findings highlight the complex interactions between grassland ecosystems and pest populations, emphasizing the importance of considering grass characteristics in pest management strategies.

The observed correlations between grass characteristics and fall armyworm (FAW) populations underscore the intricate dynamics at play within maize farm ecosystems. Previous studies have similarly highlighted the influence of environmental factors and vegetation characteristics on pest populations. For instance, (Tefera *et al*., 2011) found that higher grass biomass can provide favorable microhabitats for FAW larvae, leading to increased pest abundance. This is consistent with the current findings where higher dry weight and volume of grass were positively correlated with FAW populations across multiple sites, suggesting that greater biomass supports higher pest densities by providing ample food and shelter.

Moreover, the significant negative correlations with disturbed quadrats across various sites align with earlier research indicating that habitat disturbance can disrupt pest life cycles and reduce their populations. For example, (Prasifka *et al*., 2006) reported that agricultural practices that disturb the habitat, such as tillage, can significantly reduce pest populations by disrupting their breeding sites and reducing habitat suitability. This supports the current observation that higher levels of disturbance were associated with lower FAW populations, emphasizing the role of habitat management in pest control strategies.

The study’s findings on the impact of rainfall on FAW populations are also corroborated by previous research. (Nagoshi *et al.*, 2012) observed that FAW populations tend to decline in areas with higher rainfall, as excessive moisture can lead to increased mortality rates due to fungal infections and reduced egg hatchability. The strong negative correlation between rainfall and

FAW abundance in Vihiga and Homabay aligns with these findings, indicating that higher precipitation may create unfavorable conditions for FAW survival and reproduction.

Additionally, the influence of specific grass species, such as *Cyprus immensis* and *Cynadon dactylon*, on FAW populations aligns with studies on host plant preferences and pest dynamics. As noted by (Nagoshi *et al.*, 2012), different grass species vary in their suitability as hosts for FAW, influencing pest distribution and abundance. The significant correlations between the abundance of these grass species and FAW populations in the current study suggest that certain grasses provide more suitable habitats for FAW, thus influencing their population dynamics.

In summary, the current study's findings are consistent with previous research highlighting the multifaceted interactions between grass characteristics, environmental factors, and pest populations. These correlations emphasize the importance of integrated pest management (IPM) strategies that consider vegetation management, habitat disturbance, and climatic conditions to effectively control FAW and stemborer populations. By incorporating these ecological insights, pest management practices can be better tailored to maintain sustainable crop production and ecosystem health.

CHAPTER SIX

CONCLUSION, RECOMMENDATIONS AND SUGGESTIONS FOR FUTHER STUDIES

6.1 CONCLUSION

1. This study underscored the intricate relationship between seasonal variations, altitude, and grassland characteristics in grasslands adjacent to maize farms across western Kenya. The findings highlighted that species composition and richness fluctuate with seasons and altitudinal gradients, illustrating how grass diversity and abundance are closely tied to environmental factors such as rainfall and elevation. Assessing these seasonal and altitudinal patterns was essential for understanding how grassland biodiversity and distribution contribute to agricultural landscapes, supporting pest management strategies that leverage ecological insights for enhanced maize production.

2. This study examined the impact of altitude on grass species diversity, stemborer populations, and fall armyworm populations across four varying altitudes in Western Kenya. The findings revealed that altitude significantly influences grass species diversity, with notable similarity and diversity in grass species distribution across different elevations, consistent with prior research. Additionally, altitude significantly affected the abundance of fall armyworms in both 2019 and 2020, highlighting the role of altitude-associated environmental factors such as temperature and humidity in shaping pest population dynamics.

3. This study explored the influence of grass composition and characteristics on stemborer and fall armyworm populations in grasslands surrounding maize farms across four altitudes in Western Kenya. The findings revealed that altitude alone was not a significant factor in pest presence, with other variables like grass composition and characteristics playing more critical roles. The study highlighted the complex interplay between environmental factors and pest dynamics, emphasizing the need for integrated pest management strategies that consider multiple variables to sustain crop health and productivity.

4. The investigation into the effects of grass composition and characteristics on stemborer and fall armyworm populations in maize farms across four varying altitudes in Western Kenya

revealed this that grass composition and characteristics have a complex but significant impact on pest populations in maize fields. The variations observed between locations and seasons highlight the need for localized pest management strategies that consider regional grass composition, climate, and other environmental factors in Western Kenya.

6.2 RECOMMENDATIONS FROM THIS STUDY

1. There is need to come up with pest control measures to seasonal and altitudinal variations, focusing interventions on peak pest activity periods in each elevation zone to maximize effectiveness.

2. There is need to design pest management approaches that consider the specific grass species and their characteristics in adjacent grasslands, as these play a significant role in pest habitat suitability.

3. Promote sustainable pest control practices, such as push-pull technology and intercropping, using grass species that naturally deter pests near maize fields.

4. Educate farmers on the link between grassland biodiversity, environmental factors, and pest populations, empowering them to implement localized, ecologically-informed pest management practices.

6.3 RECOMMENDATIONS FOR FUTURE STUDIES

1. To further understand grass composition, distribution, and characteristics in grasslands adjacent to maize farms across varying altitudes in western Kenya, future studies should include long-term and expanded spatial analyses, detailed microclimatic and microhabitat data collection, and comprehensive soil health assessments. They should also investigate the impact of agricultural practices, assess biodiversity and ecosystem functions, conduct genetic diversity studies, and consider socio-economic factors influencing land use practices. Additionally, evaluating Integrated Pest Management (IPM) strategies will help optimize pest control measures while preserving grassland biodiversity. These steps aim to develop sustainable management practices that account for both ecological and socio-economic factors.

2. To explore the impact of altitude on grass species diversity and pest populations in Western Kenya, the following recommendations are proposed: Implement long-term monitoring to identify trends over multiple seasons, expand research to additional altitudinal gradients and regions, collect detailed climatic data to understand environmental interactions, and investigate microhabitat variations. Evaluate the effectiveness of Integrated Pest Management (IPM) strategies tailored to specific altitudes, study the broader biodiversity and ecosystem services of grasslands, conduct genetic studies on grass species and pests, and consider socio-economic factors and land use practices to promote sustainable agriculture. These recommendations aim to develop effective, sustainable management strategies by understanding ecological interactions at varying altitudes.

3. This study examined how grass composition and characteristics influence stemborer and fall armyworm populations in grasslands surrounding maize farms across four altitudes in Western Kenya. The findings revealed that altitude alone was not a significant factor in pest presence, with grass characteristics, climatic conditions, and habitat disturbances playing more critical roles. Positive correlations were found between pest populations and grass dry weight, volume, and percentage cover, as well as rainfall and temperature, particularly in Vihiga and Homabay. Disturbed quadrats consistently showed a strong negative correlation with pest abundance, indicating that disturbances reduce pest populations. These results emphasize the complex interplay between environmental factors and pest dynamics, highlighting the need for integrated pest management strategies that consider multiple variables to sustain crop health and productivity. Future studies should include long-term monitoring, expanded geographic scope, detailed climatic data, and evaluation of IPM practices to develop more effective and sustainable pest management strategies.

4. The study on the effects of grass composition and characteristics on stemborer and fall armyworm populations in maize farms across four varying altitudes in Western Kenya revealed significant variability in pest abundance, influenced by factors such as grass dry weight, volume, percentage cover, and climatic conditions like rainfall and temperature. The findings suggest the need for integrated pest management (IPM) strategies that incorporate these variables, regular monitoring, diversified planting practices, habitat management to reduce disturbances, climatic adaptation measures, farmer education, and ongoing research collaboration. These measures aim

to effectively control pest populations and sustain crop productivity by considering the complex interactions between pest dynamics, environmental conditions, and agricultural practices.

6.4 SUGGESTION FOR FUTURE STUDIES

1. To build on the findings from the study's conclusions, further studies should include extended temporal analysis to capture trends over multiple seasons and years. This approach will help better understand how seasonal variations and long-term environmental changes impact grass species diversity and pest populations at different altitudes. Additionally, expanding the geographic scope to include more altitudinal gradients and regions within western Kenya and beyond will validate findings and ensure they represent a wider range of environmental conditions.

2. Detailed microclimatic data collection is essential to understand how temperature, humidity, rainfall, and soil moisture interact with altitude and influence grass species composition, pest populations, and grassland productivity. Investigating microhabitat variations within each altitude will help determine how small-scale environmental differences, such as soil type, light exposure, and moisture levels, affect grass characteristics, pest dynamics, and overall biodiversity. Comprehensive soil health and fertility assessments are also necessary to understand how soil properties influence grass composition, productivity, and pest populations at different altitudes.

3. The impact of different agricultural practices and land use changes on grass composition, distribution, and pest populations should be studied to develop sustainable agricultural practices. Evaluating the effectiveness of Integrated Pest Management (IPM) strategies in these grasslands is crucial, focusing on the interaction between grass species diversity, pest populations, and environmental factors to optimize pest control measures while preserving grassland biodiversity. Assessing the broader biodiversity and ecosystem functions provided by grasslands, including their role in supporting pollinators, beneficial insects, and natural pest control agents, will help develop holistic management approaches.

4. Genetic diversity studies on identified grass species and pest populations are necessary to understand their adaptability to different altitudinal and environmental conditions, informing conservation strategies. Investigating the socio-economic factors influencing land use practices in the study areas and their impact on grass species diversity, pest populations, and agricultural

productivity will promote sustainable agricultural practices. Additionally, studying the potential interspecific competition between different pest species and the impact of environmental disturbances on pest populations and grassland ecosystems will develop strategies for minimizing negative effects and promoting ecosystem resilience.

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APPENDICES

Appendix 1: Push-pull maize farm, (00°01'667"N, 034°33'980"E) photo taken by Maryselah Nelima.

Appendix 2: Dead heart of young maize plant (00°33'551"S, 034°18'242"E) photo taken by Maryselah Nelima.

Appendix 3. Averages of the rainfall, relative humidity and temperature data recorded during the short rain season of 2019 and long rain season of 2020.

Altitude (masl)	Sites	Farm numbers	Rainfall 2020 season.	Rainfall 2019 season.	Relative humidity 2019	Relative humidity 2020.	Temperature 2019	Temperature 2020.
1400-1600	Vihiga	1	248.4	247.04	52.64	50.12	19.07	18.28
1400-1600	Vihiga	2	258.35	267.44	55.87	53.32	19.94	19.05
1400-1600	Vihiga	3	259.58	267.84	55.87	53.32	19.94	19.05
1400-1600	Vihiga	4	249.54	248.11	52.64	50.13	19.07	18.28
1600-1800	Mt. Elgon	5	245.58	206.83	51.95	48.93	19.23	18.42
1600-1800	Mt. Elgon	6	212.83	197.23	51.95	48.93	19.23	18.42
1600-1800	Mt. Elgon	7	178.57	189.26	56.62	53.09	18.4	17.49
1600-1800	Mt. Elgon	8	210.25	213.51	50.64	47.26	19.35	18.53
1200-1400	Homabay	9	240.17	224.94	57.5	55.89	19.91	18.95
1200-1400	Homabay	10	212.36	191.1	53.76	51.97	18.75	17.93
1200-1400	Homabay	11	209.89	200.23	49.8	48.7	16.64	19.29
1200-1400	Homabay	12	216.64	187.96	53.76	51.97	18.75	17.93
1000-1200	Lambwe	13	197.3	170.36	53.76	51.97	18.75	17.93

1000-1200	Lambwe	14	201.76	178.81	53.76	51.97	18.75	17.93
1000-1200	Lambwe	15	209.45	217.8	55.87	53.32	19.94	19.05
1000-1200	Lambwe	16	202.33	167.42	53.76	51.97	18.75	17.93

Appendix 4: Grass species *Cynadon dactylon,at* (00°47'452"N, 034°29'119"E) photo taken by Maryselah Nelima

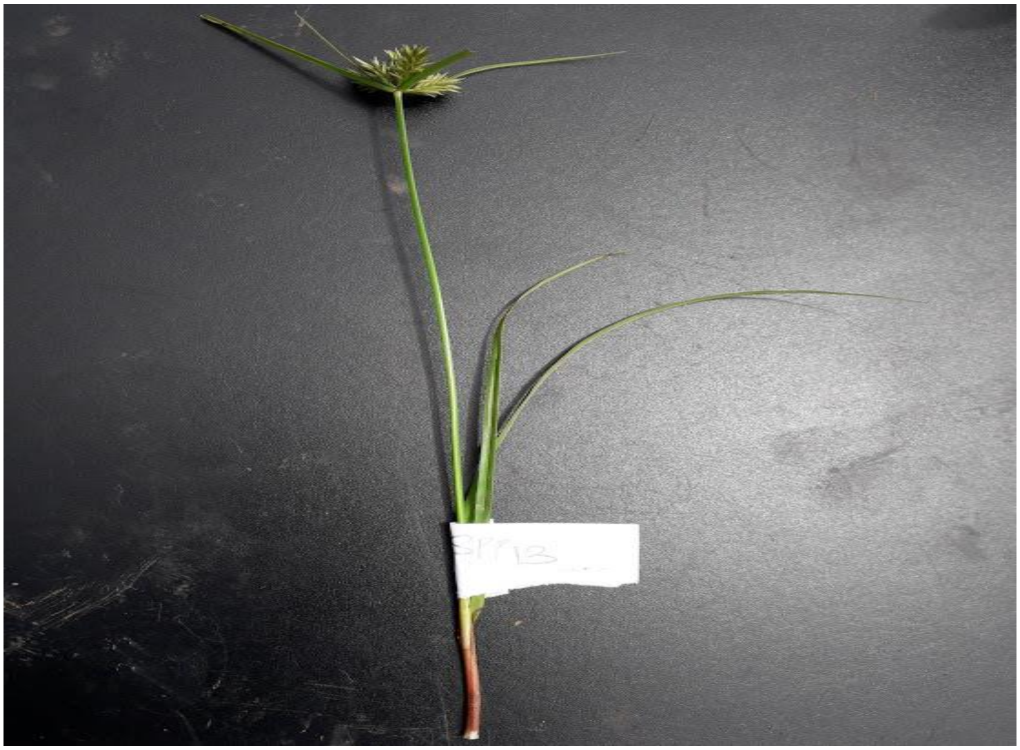
Appendix 5: Grass species *Cyprus immensis species,* at (00°05'598"N, 034°35'628"E) photo taken by Maryselah Nelima

Appendix 6: Spp 33, at (00°01'667"N, 034°33'980"E) photo taken by Maryselah Nelima

Appendix 7: *Elusine indica,* photo source http://turfweeds.cals.cornell.edu/plant.

Appendix 8. spp 5, photo taken by Maryselah Nelima

Appendix 9. spp 13, photo taken by Maryselah Nelima



Appendix 10. Spp 19, photo taken by Maryselah Nelima

Appendix 11. spp 11, photo taken by Maryselah Nelima

Appendix 12: Grass species richness and rank abundance in four study sites, Homa bay, Lambwe valley, Vihiga and Mt Elgon for 2019.

Grass species	Species rank	Abundance	Proportion
Cyprus immensis	1	28030	58.8
Cynadon dactylon	2	8162	17.1
Elusine indica	3	4619	9.7
Spp 44	4	1107	2.3
Chloris roxybarghiana	5	866	1.8
Eustachys paspaloides	6	706	1.5
Spp 13	7	467	1
Spp 8	8	433	0.9
Spp 46	9	425	0.9
Echinochloa colona	10	412	0.9
Setaria incrasata	11	364	0.8
Spp 16	12	362	0.8
Spp 19	13	207	0.4
Pilgrimis	14	171	0.4
Hyparrhenia rufa	15	169	0.4
Olumbuku	16	150	0.3
Esikondi	17	122	0.3
Cymbogon nardus	18	117	0.2
Setaria sphacealata	19	101	0.2
Spp z	20	100	0.2
Osculputa	21	85	0.2
Setaria arundenecium	22	72	0.2
Spp y	23	70	0.1

Spp z	24	55	0.1
Bothriochloa insculpta	25	55	0.1
Spp 9	26	49	0.1
Coix laxyma	27	42	0.1
Spp 33	28	41	0.1
Hyparrhenia crissata	29	40	0.1
Hyparrhenia pilgrana	30	28	0.1
Spp x	31	18	0
Oluga	32	7	0

Appendix 13: Grass species richness and rank abundance in four study sites Lambwe, Homabay, Vihiga and Mt. Elgon for 2020.

Grass species	*Species rank*	*Abundance*	*Proportion*
Cynadon dactylon	*1*	*17637*	*34.7*
Cyprus immensis	*2*	*9098*	*17.9*
Spp 33	*3*	*8476*	*16.7*
Cymbon nardus	*4*	*7951*	*15.7*
Echinochloa pyramidalis	*5*	*1326*	*2.6*
Spp y	*6*	*841*	*1.7*
Elusine indica	*7*	*705*	*1.4*
Spp 45	*8*	*492*	*1*
Brizantha	*9*	*320*	*0.6*
Spp 40	*10*	*303*	*0.6*
Spp 34	*11*	*297*	*0.6*
Spp 13	*12*	*282*	*0.6*
Spp 46	*13*	*265*	*0.5*

Spp 5	*14*	*236*	*0.5*
Spp 32	*15*	*225*	*0.4*
Spp 43	*16*	*211*	*0.4*
Spp 41	*17*	*197*	*0.4*
Spp 29	*18*	*182*	*0.4*
Spp 31	*19*	*160*	*0.3*
Esikondi	*20*	*136*	*0.3*
Trichoneura gradigumus	*21*	*134*	*0.3*
Spp 30	*22*	*130*	*0.3*
Spp 15	*23*	*128*	*0.3*
Spp 8	*24*	*127*	*0.3*
Oluga	*25*	*123*	*0.2*
Spp 20	*26*	*110*	*0.2*
Imperta cylindrical	*27*	*96*	*0.2*
Spp 19	*28*	*81*	*0.2*
Spp 16	*29*	*78*	*0.2*
Spp 27	*30*	*48*	*0.1*
Chloris roxybarghiana	*31*	*45*	*0.1*
Bothriochloa insculpta	*32*	*43*	*0.1*
Dactylocinium aegyptium	*33*	*41*	*0.1*
Spp 26	*34*	*40*	*0.1*
Spp 35	*35*	*38*	*0.1*
Hyparrhenia crissata	*36*	*27*	*0.1*
Spp 42	*37*	*24*	*0*
Osculpta	*38*	*20*	*0*
Spp 11	*39*	*19*	*0*
Pilgrimis	*40*	*13*	*0*

Echinochloa colona	*41*	*12*	*0*
Loudetia kagerensis	*42*	*11*	*0*
Spp 6	*43*	*10*	*0*
Spp 44	*44*	*10*	*0*
Spp 21	*45*	*9*	*0*
Spp 36	*46*	*8*	*0*
Spp 22	*47*	*8*	*0*
Spp 18	*48*	*7*	*0*
Spp 38	*49*	*7*	*0*
Spp 39	*50*	*4*	*0*
Spp 28	*51*	*2*	*0*
Spp A	*52*	*2*	*0*
Spp 23	*53*	*2*	*0*
Spp 37	*54*	*1*	*0*
Eragrostis superba	*55*		*0*

Appendix 14: Correlation of grass characteristics on the population of faw and stemborers on the grass surrounding maize farms

	Short Rain Season 2019		**Long rain season 2020**	
Vihiga				
	Rs	P	rs	P
Dry weighty	0.92	1.27E-04	0.92	1.27E-04
Volume of grass	0.92	1.27E-04	0.92	1.27E-04
Grass percentage cover	-0.92	1.97E-04	-0.91	1.97E-04
Rainfall	0.88	7.59E-04	0.88	7.59E-04
Temperature	0.76	1.09E-02	0.75	1.09E-02
Disturbed quadrats	-0.93	7.35E+05	-0.93	7.35E-05
Average of *Cyprus immensis* abundance.	-0.89	3.99E-04	-0.89	3.99E-04
Average of *Cynadon dactylon* Abundance	0.9	2.62E-04	0.9	2.62E-04
Homabay				
	Rs	P	rs	P
Volume of grass	0.6	6.25E-02	6.00E-01	6.25E-02
Volume of grass	0.6	6.25E-02	6.00E-01	6.25E-02
Grass percentage cover	-0.88	6.46E-04	-8.80E-01	6.46E-04
Rainfall	-0.74	1.35E-02	-5.80E-01	7.54E-02
Temperature	-0.58	7.54E-02	-5.80E-01	7.54E-02
Disturbed quadrats	-0.97	1.75E-06	-9.70E-01	1.75E-06
Average of *Cyprus Immensis* abundance	-0.72	1.70E-02	-7.20E-01	1.70E-02
Average of *Cynadon dactylon* abundance	-0.74	1.35E-02	-7.40E-01	1.35E-02
Mt.Elgon				
	Rs	P	Rs	P

Dry weight	0.09	0.78	0.097	0.78
Volume of grass	0.09	0.78	0.097	0.78
Grass percentage cover	0.17	0.63	0.17	0.63
Rainfall	-0.001	0.99	-0.001	0.99
Temperature	0.22	0.52	0.22	0.52
Disturbed quadrats	0.844	0	0.84	0
Average of *Cyprus immensis* abundance.	0.09	0.78	0.09	0.78
Average of *Cynadon dactylon* abundance	0.54	0.1	0.54	0.1
Lambwe				
	Rs	P	Rs	P
Dry weight	0.56	0.088984	0.95	2.37E-05
Volume of grass	0.72	0.01	0.95	2.37E-05
Grass percentage cover	-0.75	0.011	-0.8	5.25E-03
Rainfall	-0.72	0.017468	0.97	2.18E-06
Temperature	-0.39	0.261454	0.97	2.18E-06
Disturbed quadrats	-0.77	0.009066	-0.9	3.78E-04
Average of *Cyprus Immensis* abundance.	-0.43	0.204961	-0.95	1.62E-05
Average of *Cynadon dactylon.*	-0.14	0.680152	0.84	2.22E-03

Appendix 15: Correlation of grass characteristics on the population of faw and stemborers on maize farms

	2019, short rain season		**2020, long rain season**	
	FAW on maize farms		**FAW on maize farms**	
Vihiga				
	Rs	P	Rs	P
Dry weight	0.63	0.04	0.63	0.04
Volume of grass	0.63	0.04	0.63	0.04
Grass percentage cover	-0.72	0.01	-0.72	0.01
Rainfall	0.89	0	-0.89	0
Temperature	0.69	0.02	0.69	0.02
Disturbed quadrats	-0.68	0.03	-0.67	0.03
Average of *Cyprus immensis* abundance	-0.88	0	-0.88	0
Average of *Cynadon dactylon* abundance	0.69	0.02	0.69	0.025
Homabay				
	Rs	P	rs	P
Dry weight	0.48	1.58E-01	4.80E-01	1.58E-01
Volume of grass	0.48	1.58E-01	4.80E-01	1.58E-01
Grass percentage cover	-0.93	6.12E-05	-9.30E-01	6.12E-05
Rainfall	-0.59	7.01E-02	-5.90E-01	7.01E-02
Temperature	-0.74	1.31E-02	-7.40E-01	1.31E-02
Disturbed quadrats	-1	0.00E+00	-1.00E+00	0.00E+00
Average of *Cyprus immense* abundance	-0.69	2.42E-02	-6.90E-01	2.42E-02
Average of *Cynadon dactylon* abundance	-0.59	7.01E-02	5.90E-01	7.01E-02
Mt.Elgon				
	Rs	P	rs	P
Dry weight	-0.92	0	-0.92	0
Volume of grass	-0.92	0	-0.92	0
Grass percentage cover	-0.89	0	-0.89	0
Rainfall	1	0	1	0
Temperature	0.4	0.25	0.4	0.25

Disturbed quadrats	-0.52	0.11	0.52	0.11
Average of *Cyprus immensis* abundance.	-0.92	0	-0.92	0
Average of *Cynadon dactylon* abundance	-0.62	0.05	-0.62	0.05
Lambwe				
	Rs	P	rs	P
Dry weight	0.36	2.96E-01	0.66	0.03
Volume of grass	0.49	1.44E-01	0.66	0.03
Grass percentage cover	-0.89	4.94E-04	-0.35	0.31
Rainfall	-0.49	1.44E-01	0.84	0
Temperature	-0.65	4.18E-02	0.84	0
Disturbed quadrats	-0.53	1.07E-01	-0.53	0.11
Average of *Cyprus immensis* abundance.	-0.14	6.93E-01	-0.64	0.04
Average of *Cynadon dactylon* abundance	-0.34	3.28E-01	1	0