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Impact of climate change and management cost of chromolaena odorata on maize production for smallholder farmers in Serengeti District, Tanzania

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IMPACT OF CLIMATE CHANGE AND MANAGEMENT COST OF *Chromolaena odorata* ON MAIZE PRODUCTION FOR SMALLHOLDER FARMERS IN SERENGETIDISTRICT, TANZANIA

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A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master's in Life Sciences at The Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Chromolaena odorata is a weed that has infested agricultural land in the Serengeti district and adversely reduced cropland and crop yield. This study evaluated the impact of climate change and the management cost of *Chromolaena odorata* on maize production in the Serengeti District. Firstly, the available roads were used as line transects for *Chromolaena odorata* observation. Global Position System coordinate collected was used to generate a distribution map of *Chromolaena odorata* in the Serengeti district. Climate change impact on maize production was assessed using maize production data from 2000-2018 from the Serengeti District office. Climate data were from the Grummet Game reserve. Correlation analysis was used and the results showed rainfall and maize production were positively correlated, ($r = 0.08$ and $p = 0.73$). Mean annual temperatures and maize yield were positively correlated, however, the correlation was not significant ($r = 0.47$ and $p = 0.12$). Therefore, the climate in Serengeti was not only the factor for the decline in maize yield. A field trial was performed in Serengeti to investigate the management cost and frequency of weeding on the growth and yield of maize, and to determine the best frequency of weeding to get an optimum yield. There were five treatments replicated four times. Treatments were; No weeding, weeding once, twice, thrice, and fourth. The highest yield was obtained in weeding four times treatment with 2403 kg/ha with significantly different ($P<0.05$, $P=0.014$). The lowest yield was obtained in no weeding treatment with 520 kg/ha. There was an addition of 1883 Kg. ha^{-1} of maize grain yield equivalent to a 70% increase Marginal return rate in weeding four times treatment. This study suggests that for better maize yield and profit farmers should perform weeding four times to control *Chromolaena odorata* on their cropland.

DECLARATION

I, Monica Elimwaria Makere, do hereby declare to the Senate of The Nelson Mandela African Institution of Science and Technology that this dissertation is my original work and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

Monica Elimwaria Makere	Makere	3/8/2022
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The above declaration is confirmed by:

Prof. Linus Munishi	Munishi	04/08/2022
Name of Supervisor 1	**Signature**	**Date**

Prof. Patrick Ndakidemi		
Name of Supervisor 2	**Signature**	**Date**

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CERTIFICATION

The undersigned certify that they have read and hereby recommend for acceptance by The Nelson Mandela African Institution of Science and Technology, a dissertation titled **"Impact of climate change and the management cost of *Chromolaena odorata* on maize production to small holder farmers in Serengeti District, Tanzania"** in partial fulfillment of the requirements for the degree of Master's in Life Sciences of The Nelson Mandela African Institution of Science and Technology.

Prof. Linus Munishi	Okasion	04/08/2022
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Prof. Patrick Ndakidemi		
Name of Supervisor 2	**Signature**	**Date**

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DEDICATION

I dedicate this Dissertation to God Almighty, my creator, my strong pillar, and my source of inspiration, wisdom, knowledge, and understanding. He has been the source of my strength throughout this research, and on His wings only have I soared. I also dedicate this dissertation to my beloved parent Mr. and Mrs. Elimwaria, who has encouraged me all the way and whose support has made sure that I give it all it takes to finish this work. Further dedications go to my beloved sisters for their prayers, encouragement, and support during this work. Thank you. My love for you all can never be quantified. God bless you.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
C. odorata	*Chromolaena odorata*
DAE	Day After Emerging
DAS	Days After Sowing
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GISD	Global Invasive weed Database
GPS	Global Position System
HSD	Honest Significance Difference
HSD	Tukey's Honest Significance Difference
IAS	Invasive Alien Species
ITK	Indigenous Technical Knowledge
MNR	Marginal Net of Return
MRR	Marginal Rate of Return
NM-AIST	The Nelson Mandela African Institution of Science and Technology
SDG	Sustainable Development Goals
TIAP	Traditional and Indigenous Agronomic Practices
TVC	Total Variable Cost
URT	United Republic of Tanzania
USA	United States of America
WAE	Week After Emerging

CHAPTER ONE

INTRODUCTION

1.1 Background of the Problem

In developing countries, small farmers produce a large percentage of food. However, they are worse off than the rest of the population in terms of food security. One of the significant challenges comes from the invasive weed species, which pose a real challenge to farming by increasing economic costs and declining yields (Hoffmann & Broadhurst, 2016; Nghiem *et al*., 2013; Paini *et al*., 2016). Invasive weeds present serious threats to the agriculture sector, with significant adverse impacts on local livelihoods, for instance, by amplifying about 40% of production costs (Shackleton *et al*., 2019). The number of invasive weeds is expected to increase and spread with further escalation of agricultural systems' impacts. As the invasion threats are on the rise, other global changes and challenges (e.g. climate change, degraded soils, insufficient arable land) exacerbate current food production, causing grave concern for future food security and the local population's economy and livelihood prospects (Lobell *et al*., 2008; Pimentel *et al.,* 2001; Shackleton *et al.,* 2019).

Over the next three decades, agricultural areas are expected to experience a farming season with higher temperatures than the present condition, exacerbating the current invasions and facilitating new ones (Pyšek *et al.*, 2020). Crop production will be affected in several ways. For example, the invasion threat on the maize crop, which comprises the top 75% of the total value of agricultural output for most developing countries, including Tanzania, is likely to be significant in the future, given that most of its areas are infested with invasive pests and pathogens. Similarly, the Sub- Saharan African agricultural sector is at risk of invasive weeds, resulting in lower productivity (Pimentel *et al.,* 2001; Simberloff *et al*., 2013). However, it remains unclear how far invasive weed species have on smallholder farmers' social and economic aspects.

The agriculture sector is critical to Tanzania's economy with the prospect of advancing the country’s development agenda. The sector has the largest share in the economy and employs most of the poor and linkages to other sectors. It accounted for 15% of foreign exchange in 2004, as well as 75% of total employment, and 47% of the GDP (Amani, 2005). Despite its importance, agriculture production in Tanzania faces many challenges, including weak infrastructure, over-dependence on rainfall, weak support services, and climate-related disasters, namely flooding, droughts, and ecological changes for pests and diseases (Amani, 2005; Omambia & Gu, 2010) Apart from such challenges, invasive weed species are also becoming a threat, especially in managing maize crops production as they invade and compete with crops for moisture, light, and nutrients (Pratt *et al*., 2017). In Serengeti District, *C. odorata* is among the heavily invaded weeds in cropland (Shackleton *et al.*, 2017). This study seeks to assess the impact of climate change and quantify the effect of *C. odorata* on maize production for smallholder farmers in North-Western Tanzania. Findings generated from this study will inform stakeholders to design cost-effective management plans for the mitigation of *C. odorata* in Tanzania and beyond.

1.2 Statement of the Problem

Invasive weeds present are threats to the farming sector, with varying effects between countries and regions (Paini *et al.*, 2016). Invasive weeds have caused a severe reduction in food production, leading to loss of income and increased livelihoods vulnerability (Pratt *et al.*, 2017; Shackleton *et al*., 2019). The spread of the noxious invasive weed *C. odorata* is accelerating in Serengeti District in north-western Tanzania (Shackleton *et al*., 2017). *Chromolaena odorata* grows in various areas ranging from forests and grasslands to both bushlands and cropland. In most cases, *C. odorata* out-competes with other species in terms of space and nutrient access, causing natural ecosystem degradation, and reduced crop yields and quality (Muzzo *et al*., 2018). Although crop production has been adversely affected by this invasion, the livelihoods and sustenance of farmers, pastoral and agro-pastoral communities in the area remain largely threatened by this weed. Moreover, farmers in the area have been observed to lose the battle against *C. odorata* by abandoning their cropland. Most of the cropland in western Serengeti has been invaded by *C. odorata*, and several measures have been taken to control its spread and growth in agricultural fields, mainly by chemical and mechanical removal. The methods are considered unsuccessful, as *C. odorata* is still spreading and growing in agricultural land, causing a yearly decline in agriculture yield and increasing production costs.

1.3 Rationale of the Study

Until now, it is unclear about the current extent of the occurrence and distribution of *C. odorata* within and around agricultural land in Serengeti. How much costs and loss do farmers incur by having this species in their productive land, and the best adaptive strategies for management of *C. odorata*. Therefore, this focuses on assessing the invasion of *C. odorata* in Serengeti cropland by establishing the distribution and costs of management farmers are incurring by having *C. odorata* in their agricultural land. Smallholder farmers need relevant, cost-effective adaptive strategies that they can use to get the optimal crop yield from their invaded land.

1.4 Objectives

1.4.1 General Objective

To assess the impact of climate change and management cost of *C. odorata* on maize production to smallholder farmers in Serengeti District, Tanzania.

1.4.2 Specific Objectives

(i) To map the current areas invaded by *C. odorata* in Serengeti District, Tanzania.

(ii) To assess maize production patterns in relation to climate change in the Serengeti District.

(iii) To establish the management costs and yield between non-infested and infested croplands with varying intensities of *C. odorata* in Serengeti cropland.

1.5 Research Questions

(i) What is the distribution status of *C. odorata* in the Serengeti area?

(ii) What is the trend of maize crop production growing by smallholder farmers in relation to climate in the Serengeti District?

(iii) What are the differences in production management costs and yield between invaded and on-invaded areas in Serengeti area?

1.6 Significance of the Study

This study revealed up-to-date information on the spatial distribution and invasion of *C. odorata* in the Serengeti district which will help stakeholders and policymakers to come up with better management action. Evidence from the field shows weeding practices improve maize production in the Serengeti district. It synthesizes and recommends potential cost-effective weeding practices for management of *C. odorata*, to the advantages of the decision-making process and stakeholders' actions.

1.7 Delineation of the Study

This study seeks to assess the impact of climate change and quantify the effect of *C. odorata* on maize production for smallholder farmers in North-Western Tanzania. This study conducted a field survey, to determine the distribution of *C. odorata* in the Serengeti District and a field trial for the yield of maize and management costs. The field survey involved data collection through road transects and collection of Global Positioning System (GPS) coordinates for producing a distribution map. Findings generated from this study will inform stakeholders to design cost-effective management plans for the mitigation of *C. odorata* in Tanzania and beyond.

CHAPTER TWO

LITERATURE REVIEW

2.1 Biological Invasion

Biological invasions have increased rapidly in recent decades around the world. Invasive Alien Species (IAS) lead to a large and increasing threat to biodiversity, and the magnitude of this threat is increasing globally (McGeoch *et al.,* 2010). Invasive alien species alter ecosystem processes Raizada *et al.,* (2008), leading to the reduction of native species richness because of competition, predation, and altering the structure of the community (Gaertner *et al*., 2014). Increases in the number and spread of IAS are related to increases in the volume of trade and transport, over the last two decades (Hejda *et al*., 2009). Whereas global trends in trade are well known, trends and patterns related to IAS and related effects on biodiversity and people's countermeasures to such effects are not well researched. Likewise, such invasive weed negatively affects ecosystem services, such as water supply, reduces grazing land, affects soil quality, as well as reduces crop production (Pratt *et al.*, 2017). *Chromolaena odorata* is among the invasive weed species introduced to new locations worldwide, including Tanzania (McFadyen & Skarratt, 1996), and has later become highly invasive and damaged agricultural land and natural systems (Aigbedion *et al*., 2019).

2.2 The Biological and Ecological Aspects of *C. odorata*

Chromolaena odorata is a perennial shrub. It establishes dense tangled bushes measured between 1.5-2.0 m in height, scrambling trees up to 6 m (Fig. 1). It is a flowering plant that produces enormous numbers of seeds, up to about 1 million seeds per plant per flowering season (Paterson & Zachariades, 2013). The species grows rapidly under favorable weather conditions. *Chromolaena odorata* flourishes in locations characterized by an annual rainfall below 1000 mm, as far as the dry season is short. *Chromolaena odorata* grows to around 2000 m altitude and cannot endure frost. It grows on soils ranging from dunes to heavy clays (Liggitt, 1983). It is highly competitive, reproduces easily and expands rapidly, and tends to dominate native vegetation. Its approximate life span is ten years (McFadyen, 2004). *Chromolaena odorata* flourishes around October, and thereafter sporadic flowers commence. The reproduction occurs mainly through seeds. The plant grows vegetative until November-December, reaching a height of 80-150 cm. Flowering starts mid-December, and seeds mature by March-April. The seeds emerged immediately after maturation. The process of germination starts with the beginning of rains in April-May (McFadyen & Skarratt, 1996). *Chromolaena odorata* is perceived to be a major weed across all perennial crops found in the humid tropics and forests. Its aggressiveness is much more serious in the old-world tropics, where it is exotic, rather than in its native America. *Chromolaena odorata* is located largely in the humid side of inter-tropical zones whose elevations are below 2000 m (Zachariades *et al.*, 2009). They end up in an open secondary habitat occupied by farmed lands, abandoned fields, wastelands along roadsides, and forest margins (Zachariades *et al.*, 2009).

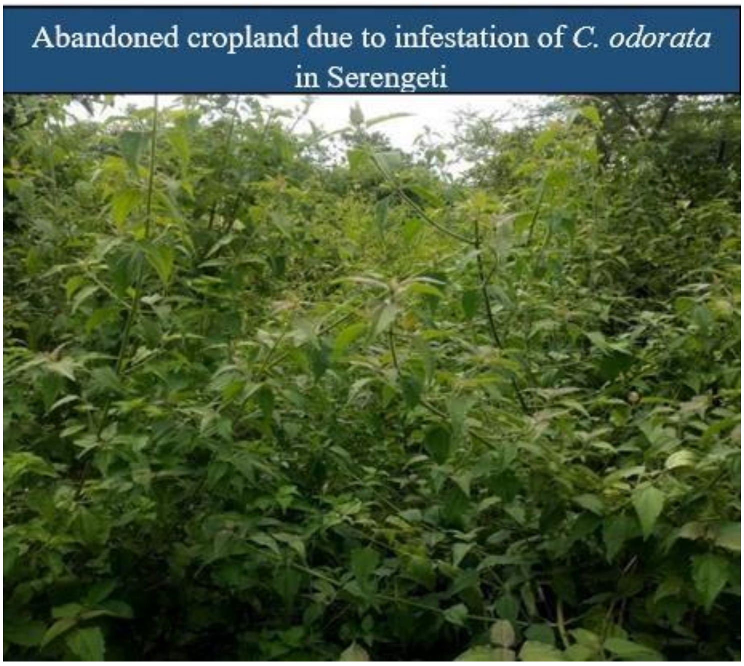

Figure 1: Abandoned cropland due to infestation of *C. odorata* in Serengeti District

2.3 Distribution of *C. odorata*

C*hromolaena odorata* is a native shrub that originates from the Southern United States of America (USA) to the South American side of Northern Argentina. Over the past decades, C. odorata has become invasive in subtropics and humid tropic regions of the world, including invading into African countries of Angola, Zambia, Malawi, Mozambique, North-Eastern Botswana, Southern Sudan, Tanzania, Kenya, Sierra Leone, Gambia, Southern Senegal and Burkina Faso (Gautier, 1992). The invasive weed was first reported in Tanzania by McFadyen and Skarratt (1996), the weed was however reported in 2007 to have been spotted in north-western Tanzania (Mara region). It is perceived to have been brought by wind accidentally (Zachariades *et al.*, 2009). To date, it is considered an aggressive weed in Serengeti District. It is fast maturity which implies that it is likely to spread in large locations. *Chromolaena odorata* flourishes in varying habitats. Reference is made to habitats ranging from forests, grasslands, and bushlands to grazing and farmed pieces of land (Foxcroft *et al.*, 2013).

2.4 Impact of *C. Odorata* on Agricultural Systems

To the agriculturalists, there is no doubt that *C. odorata* not only competes with crop plants for nutrients and light (and ultimately reduces crop yields) but also reduces the size of land for cultivation. It has other deleterious effects on crop production (Shackleton *et al*., 2017), including impeding access to a plantation. As stems tend to partially dry during the hot season, there is a risk for the species to cause a fire. Fungi, such as *Fusarium* spp and *Fusarium exosporium* are harbored within the seeds of the weed. These are pathogens of food crops like rice, and chili pepper leading to disease in crops such as oil palm. The problem of *C. odorata* is serious in the early stages of plantation crops, such as oil palm, cocoa, and rubber, where growth is initially slow. Specifically on oil palm, *C. odorata,* if uncontrolled can result in a large decline in the dry weight of oil palm seedlings during the stage of the nursery (Goodall & Zacharias, 2002). Moreover, the weed can result in destructive shading and smothering of young palms. The weed tends to dominate the leguminous covers that are planted in the interline (Norgrove *et al*., 2008).

This invasive plant species has also been spreading fast in several parts of Tanzania from the Northern-Western (Serengeti & Tarime), and central parts to North-Eastern Tanzania. As a result, it has been destroying palatable species and other pastures, as well as causing other menaces in livestock. Forage production has been largely affected by the spread of this weed, mocking the already existing problem of the dry season that threatens livestock existence, which negatively affects pastoral and agro-pastoral livelihood. The implications of this impact of *C. odorata* on smallholder farmers in Serengeti are its role in food security. Infestation of croplands by *C. odorata* reduces the land potential for agriculture and food production, which sometimes makes food production more costly (URT, 2019). The agricultural lands in Serengeti have been invaded by *C. odorata* (Fig. 2), which has caused reduced land for agricultural activities and also lowered yield production yearly. The *C. odorata* have so far outcompeted the crops in most of the village land.

Figure 2: ***Chromolaena odorata*** **infestation in cropland in Serengeti District**

2.4.1 Impacts of *C. odorata* on Arable Crop Production

The invasion of *C. odorata* in arable agricultural fields not only decreases yields of maize and cassava but also reduces farmers' profit including limiting farmers from engaging in other farming activities. The weed also accommodates fungi, which affect crops (Uyi *et al*., 2014). The yield of a crop like maize is known to have been reduced by the weed by around 17%, while cassava is between 60-70% (Sangakkara & Stamp, 2006). However, how the weed exerts its destructive effects on food crops is not fully understood. Its competitive ability for nutrients and light has a destructive effect on the crops. Its growth may also have an allelopathic effect on the crops. In India, the leaf extracts of the weed are considered to be toxic to mustard and wheat (Uyi *et al*., 2014). Largely, the impacts of an invasive weed in the agriculture sector have been generalized to include: reduced cash income from crop production, increased farming costs, reduced food security, increased livelihood insecurity, and increased public expenditure, e.g., on food relief and breeding of disease-resistant varieties (Lyimo *et al.*, 2009).

2.5 Uses of *C. odorata*

Chromolaena odorata is traditionally considered and used for several medicinal properties, including skin infections, treating wounds, and inflammation. Scientific literature shows that the extracts from the leaf are antioxidant, anti-inflammatory, analgesic, anti-microbial, and cytoprotective to mention a few. Other studies in the field of phytochemicals have confirmed a wide range of chemical entities in the plant. Phytochemical constituents such as tannins, flavonoids, and alkaloids of plants serve as a defense mechanism against predation by many microorganisms, insects, and herbivores (Akinmoladun *et al.*, 2007).

2.6 Invasiveness of *C. odorata*

Apart from being a useful species, *C. odorata* is considered a highly invasive weed. *Chromolaena odorata* is recorded as one of the global's 100 worst invaders (Global Invasive weed Database [GISD], 2019). The specie is also a category 2 invader in South Africa, as well as categorized as a noxious environmental weed in the global compilation of invasive weeds (Vásquez *et al*., 2015). Its invasiveness is an outcome of its capacity to negatively affect people and the environment, including land degradation. It negatively affects biodiversity by dislodging native plants, prompting allelopathy, altering soil properties, and reducing grazing potential for wildlife and livestock. It is known to increase the intensity and occurrence of fires in areas occupied by natural forests. It also negatively affects livelihoods, because of the loss of grazing and agricultural land. The specie aggressively competes with food crops in southern Cameroon and is among the foremost weed in slash-and-burn farming areas (Ngobo *et al.*, 2004).

2.7 Control measures of *C. odorata*

According to Zachariades and Goodall (2002), *C. odorata* can be controlled through mechanical, biological, and chemical methods. By mechanical control, the seeds and young plants can be removed by hand pulling. However, clearance is needed every 2-3 months because of rapid regrowth. Biological control has been achieved through the use of the insect *Pareuchaetespseudoinsulata* (Kluge, 1991). However integrated control strategies are being experimented with because of the limited success achieved through the release of biological control agents. Such means refer to either excluding fire or applying fire before the seed is released to kill plants and soil-stored seeds immediately before seed production (Ngobo *et al*., 2004). This is done together with chemical/physical clearing as well as efforts to maintain people's awareness which is a crucial factor for the management of *C. odorata* (Ngobo *et al*., 2004).

2.7.1 Challenges Associated with the Management of *C. odorata* in Serengeti District

Tanzania's smallholder farmers have an important role in food security. However, an infestation of croplands by invasive weeds reduces the land potential for agriculture and food production, which sometimes makes food production more costly. More than 21 villages in Serengeti have been infested with *C. odorata*. About 90% of the croplands have been invaded by *C. odorata*, which has caused reduced land for agricultural activities but also lowered yield production yearly. For their adaptive and dominant characteristics, invasive plant species. *Chromolaena odorata* embeds the capacity to out-compete the native species and grow extensively in croplands (URT, 2019). The *C. odorata* in the Kenyamota, Nyichoka Kwitete villages have so far outcompeted the crops in most of the village land (Personal observation). Largely, the impacts of an invasive weed in the agriculture sector have been generalized to be: reduced cash income from crop production, increased farming costs, reduced food security, increased livelihood insecurity, and increased public expenditure (URT, 2019). Currently, control is through mechanical removal, but farmers are seeking a solution using Indigenous Technical Knowledge (ITK) and seeking scientific help, as it threatens their farming and livelihoods (DLOs Serengeti Districts reports). The challenges related to capacity for managing *C. odorata* in Serengeti District include limited knowledge and awareness of invasive weed C. odorata, the insufficiently coordinated mechanism in communication and implementation policy and legal framework both within and across borders and sectors, insufficient intra-and inter-sectoral guidelines on managing invasive weed, insufficient facilities and limited funds to enforce regulations for managing *C. odorata* and other invasive weed (URT, 2019).

2.8 Climate and Socio-Economic Activities in Serengeti District

The overall climatic condition of the district is conducive. The temperatures in the district depend on the rainfall patterns. During the first rains between August – December and the second rains between February-April, the average temperature is 24 ℃, while in the dry season the average temperature is 26 °C. The district has a bimodal rainfall pattern with a short rainfall period between September and January, and a long rainfall period between February and June. Crops production and livestock keeping are the major socio-economic activities in the area (URT, 2003). Also, many tourist attractions occupy 10 373 km^2, out of which about 7000 km^2 belongs to the Serengeti National Park. Other areas are 189.68 km^2 Ikorongo Game Reserve, 68.37 km^2 Grumeti Game Reserve, and an open area of 2456 km^2. The remaining area of 659 km^2 is in the area for agriculture, livestock keeping, and residence (URT, 2003).

2.8.1 Maize Production Trends in the Serengeti District

Serengeti District is the second district with the least households in the Mara region, and it is the second-highest percentage of households engaging in smallholder agriculture in the region. Most of the smallholders are occupied with crop production only, followed by livestock keeping. The most important livelihood activity for smallholders in the district is farming

(URT, 2003). Majority of the people in the district (90%) are engaged in agricultural undertakings (farming) 90%. The District Gross Domestic Product is estimated to be TZS 31 045 573 944 per year. Hence the Per Capita income is TZS 650 000 per year compared to the National Per Capita Income of TZS 869 436 per year (URT, 2003). Food crops production in Serengeti District is small-scale holdings using traditional low efficient methods of the ethnic groups residing in this area. An increase in food production to meet population growth requirements in western Serengeti is mainly based on the expansion of cultivated land. Generally, households with less than 200 kg per capita per year are considered to be food insecure. This implies that western Serengeti experienced periods of food insecurity (Kavana *et al.*, 2017).

CHAPTER THREE

MATERIALS AND METHODS

3.1 The Study Site

The study was carried out in Western Serengeti, located in the eastern part of the Mara region, and lies at 1° 30S 2° 40S, and 34° 15' E 35° 30'E of the equator (Fig. 3). The district covers 10 373 km^2, with 659 km^2 being utilized for agriculture, livestock keeping, and residence. The district has three Agro-ecological zones, namely high, middle and low lands. The climatic conditions in Serengeti are characterized by warm and dry weather. The mean temperature is 26 °C. The area typically experiences a double rainy season; prolonged rainy occurs from February to May, and a short rainy season occurs from August to December. The annual range of rainfall in the district varies between years and across a spatial gradient from 650 mm in the lowland to 1500 mm in the highland. Agro-pastoralists are the main ethnic group in Western Serengeti. Western Serengeti is among the most densely populated areas in the greater Serengeti ecosystem. The population growth rates in that area are higher than the ones in the north, east, and south of the National Park (Kavana *et al.*, 2017).

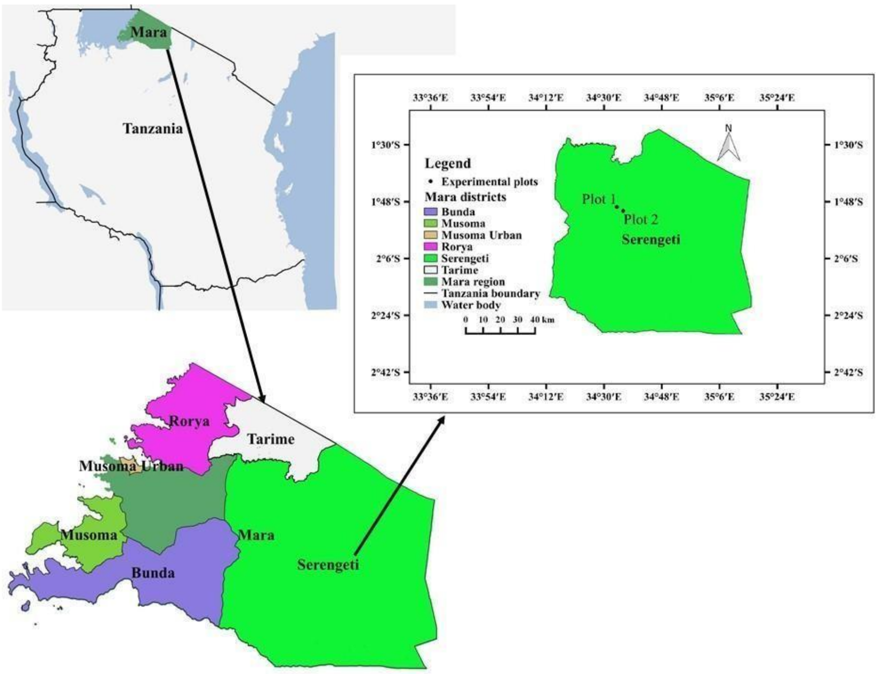

Figure 3: The study area (Serengeti District)

3.2 Sampling Design and Data Collection

3.2.1 Distribution of *C. odorata* in Western Serengeti

A reconnaissance survey was conducted between December 2019 and January 2020. *Chromolaena odorata* distribution data were collected. A district agricultural officer and field officer were engaged to identify and demarcate villages where *C. odorata* infested the study area. The available roads were used as line transects to spot *C. odorata* distribution in the area. Buckland *et al.* (2005) recommended the use of roads as transects in case an extensive area is covered by the study. A buffer off-road walk distance of 50 m from the transect road to the interior was adopted to reduce bias in observation and edge effect. A systematic sampling technique was employed in the study, whereby at least every 100 m distance a coordinate was taken where there is a high infestation of *C. odorata* (Buckland *et al*., 2005). A total of Global Position System (GPS) coordinates of 340 points of *C. odorata* infestation were collected. Global Position System Garmin 64S, a handheld device was used to attain coordinates on *C. odorata*. Also, distribution data of *C. odorata* was collected in the district near the study area to mark the succession of *C. odorata* in the Mara region.

3.2.2 Maize Production and Climate Change in Western Serengeti

The monthly data on average temperature and rainfall were sourced from the Grummet game reserve from the year 2000 to 2018. Grummet Game Reserve facilitates the gathering of climate data and monitoring. Estimates of Serengeti district maize yields for 2000-2018 were obtained from the District Agriculture and Livestock Office. Seasonal estimates from the available Serengeti cropland area data were computed for maize crops, with both commercial and smallholder rain-fed sectors (Munishi *et al.*, 2015).

3.2.3 Management Cost of Production and Yield of Maize in Areas with and without Infestation of *C. odorata*

A preliminary survey was conducted in areas with a high infestation of *C. odorata*, in which maize crops were cultivated in the Serengeti district. The selection of the site was chosen based on a high infestation of *C. odorata*, the cultivation history of the land, and common local practices in managing *C. odorata* during maize crop production. The site was selected in areas with a high infestation of *C. odorata*, cleared and plowed, usually done on most community farms to allow experimental layout.

The field experiment was conducted during the rainy season (March to July 2020). At the field site, a randomized complete block design with 4 replications and 5 treatments was carried out. Plots' size of 5m x 4m (20m^2) was used. Naturally occurring other weed populations, except *C. odorata,* were carefully uprooted with hand pulling without damaging the maize plant. The setting up of the *C. odorata* management practices in the field trial site of this study was in the following order: T1) No weeding (Control); T2) Weeded throughout (four times); T3) Weeded once; T4) Weeded twice. T5) weeded thrice. These treatment categories (T1 to T5) were based on informed management practices conducted by local communities in the Serengeti District as strategies for dealing with *Chromolaena odorata* infestation in their cropland. Land preparation was done by ox plowing, two seeds per hole of DK 8031 hybrid maize variety suitable for dry areas which takes three months to mature and planted at a spacing of 30 x 75 cm. Urea 5g per plant was applied as top dressing at 6 weeks after sowing.

The parameters measured were from 5 randomly selected plants and it included the following. Plant height (cm) was determined using a graduate tape measure by measuring maize plant height from above the ground level to the top during the harvesting period. The number of leaves per plant was counted and recorded at harvest time. Stem diameter was determined by measuring the diameter of the plant using graduated tape. Cob weight (g) per plant was taken after weighing on a weighing balance and then the average of the total cob weights was recorded as the cob weight/plot. Grain yield was determined by weighing the grains harvested from each net plot which was converted to kilograms per hectare. The harvesting was done on the 17 of July 2020.

Figure 4: Land preparation, plantation, and 1 week after emergence (WAE) of maize

3.3 Data Analysis

3.3.1 Distribution of *C. odorata* in Western Serengeti

The data on the spatial distribution of *C. odorata* in the study area were assessed using Arc GIS (Arc Map version 10.6) which ultimately generated the distribution map (Huang *et al*., 2016). To analyze *C. odorata* distribution, the GPS coordinates obtained during data collection were compiled and thereafter transformed into shape files format. The Kernel density tool found in the arc map version 10.6 was utilized to calculate the spatial distribution pattern of *C. odorata* across the landscape to create a continuous surface with a search radius of 1 km. Kernel tool computed density units from the linear unit of the projection of output spatial reference.

3.3.2 Maize Production Trends in Relation to Climate in Western Serengeti

To have an understanding of how climate change affects the production of maize crops in the Serengeti district, 18 years of data were utilized. The utilized data were used to compare the patterns of climate and annual maize production. Cereal crops are the ones mostly affected by variations in temperature and rainfall in Serengeti District. Maize crop production data were documented for the past decade (Munishi *et al.,* 2015). Relationships between maize production data and climate from 2000 to 2018 were subjected to a Microsoft excel sheet for correlation analyses.

3.3.3 Management Cost of Maize Production and Yield in Areas Infested with *C. odorata*

The maize growth parameters and yield data were entered into MS Excel sheets, followed by the generation of descriptive summaries and graphs. One-way Analysis of Variance (ANOVA) was used to assess variation between treatments. These computations were undertaken using the software program STATISTICA (Stat Soft Inc., Tulsa, OK, USA, 2011), and significant means were separated based on Tukey's Honest Significance Difference (HSD) Test at $p \leq 0.05$.

The comparative economic benefits and losses of *C. odorata* invasion in maize fields were estimated using simple economic analyses described by Ndakidemi *et al.* (2006). The profit or Marginal Net of Return (MNR) was calculated for each treatment:

$$\boldsymbol{MRN = Y\ x\ P\ -\ TVC}$$

Where Y is the grain yield of maize in kg/ha, P is the selling price of maize at harvest (USD/Kg), and TVC is the Total Variable Cost of inputs related to treatments (i.e., land preparation, seeds, fertilizer, management cost, etc. in USD/ha). The cost associated with inputs and labor charges incurred is maize seeds, fertilizer, pesticide, land preparation, planting, weeding, insecticide, fertilizer application, and harvesting cost.

The Marginal rate of return (MRR) represents a return on investment. The calculation was done from the least costly treatment to the costliest treatment to identify the treatment with the highest returns. This was computed using the formula:

$$\boldsymbol{MRR = MNR/TV}$$

The interest rate on money spent in sourcing farm input was set at 5%, and the costs and labor charges were fixed during this study based on local payment rates, while the selling price of maize grain yield at harvest was fixed at $ 0.26/Kg. Table 1 presents the costs of inputs used for computing profits, while Table 2 presents the labor costs for field operations.

Table 1: Costs of inputs used for computing profits

Input	Amount/ha	Unit price (USD)	Total cost (USD)
Maize seeds	25Kg	2.6	65
Fertilizer	150Kg	0.47	70.5
Pesticides	375 mls	0.02	7.6

Table 2: Costs and labour charges for field operations

Activity	Land preparation	Planting	Pesticide application	Urea application	Harvesting cost
Cost (USD)	43.5	13	4.3	6.5	30

Table 3: Cost of weeding

Activity	Weeding (1 time)	Weeding (2 times)	Weeding (3 times)	Weeding (4 times)
Cost (USD)	14.3	28.5	42.8	57.2

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Distribution of *C. odorata* in Serengeti District

Serengeti district area has two major categories of land use, which are wildlife conservation lands and agricultural lands. Most of these areas have been dominated by a high infestation of *C. odorata* (Fig. 5). Other land uses that are interwoven within the two main-land use types, are settlements and grazing land. Areas with the highest infestation of *C. odorata* weed were found in high and low slopes, abandoned cropland, roadsides, and villages throughout the study sites. These villages include Kwitete, Masangura, Nyanungu, Mesaga, Majimoto, Nyichoka, Msati, and Kibeyo, and other areas nearby the Serengeti District. Figure 5 illustrates the distribution and population density of *C. odorata* in Western Serengeti.

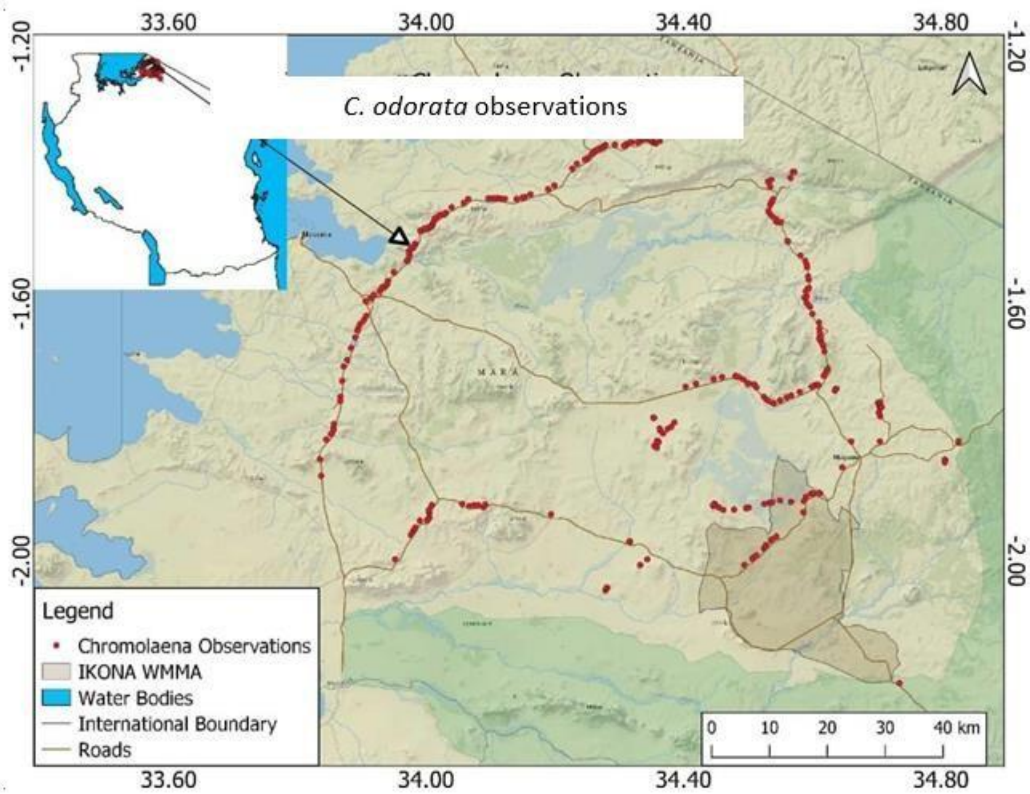

Figure 5: Distribution map of *C. odorata* in Serengeti district

4.1.2 Relationship Between Climate and Maize Production in Serengeti District

The Pearson correlation coefficient (r) and confidence interval levels of 0.05, 0.01, and 0.001 were used in this study to determine the relationship between yield and climatic variables. The total annual rainfall and mean annual temperature patterns in the Serengeti district from 2000 to 2018 experienced dramatic changes. The results from Figures 6 & 7 provide a general exploration of the maize production pattern in the study area based on the mean annual temperature and rainfall amount. The results showed that the mean annual temperatures and maize yield were positively correlated, however, the correlation is not significant (r = 0.47 and p-value = 0.12). The mean annual temperature of the region from the year 2000-2018 growing season seems to be below 26℃ which is the maximum annual temperature of the area. Also, the study showed that rainfall and maize production were positively correlated, however, the correlation is not significant (r = 0.08 and p-value = 0.73 (Fig 8). From 2000-2014 and 2018 years, the increase and decrease in mean annual rainfall do not show any influence on the maize yield. In the year 2017, there was a decrease in rainfall in the study area, but maize production was raised. These results depict the widest context of maize yields and climate in the Serengeti District. This indicts that rainfall in the study area is not only the factor for the decline in maize yields.

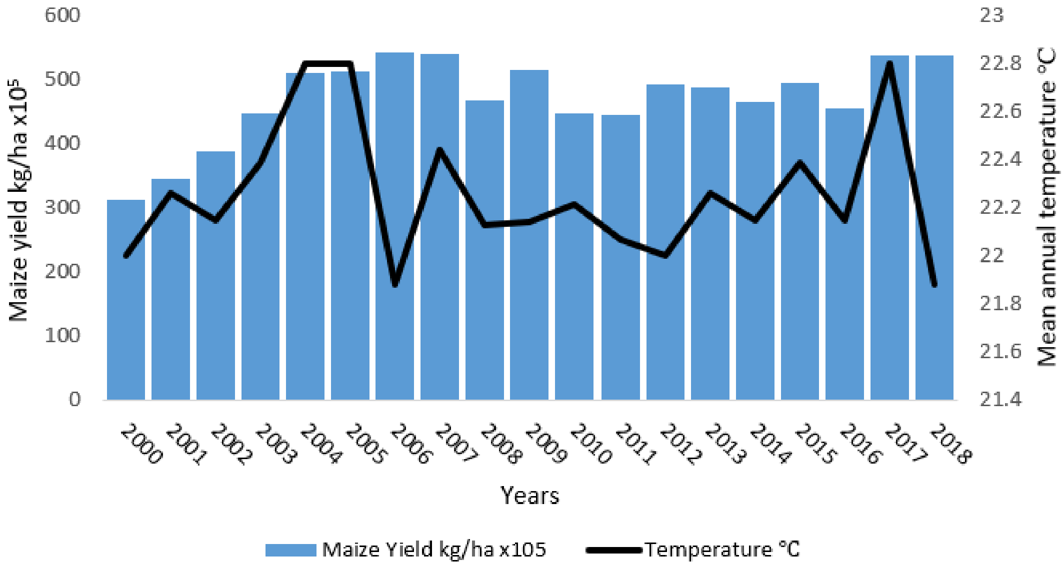

Figure 6: Annual maize output and temperature pattern in Serengeti from 2000 to 2018

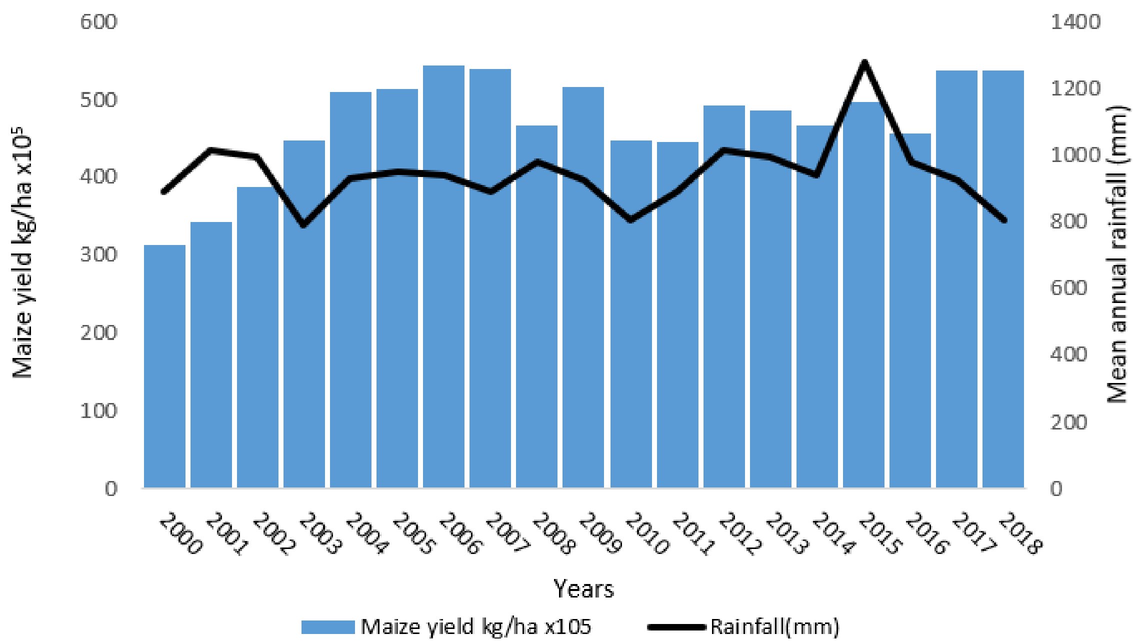

Figure 7: Annual maize output and rainfall pattern in Serengeti District from 2000 to 2018

4.1.3 Maize Crop Production Trends from 2000 To 2018 in Serengeti District

The average maize yield for Serengeti District from 2000 to 2018 ranged from 312.85 x 10^5 kg ha−1 to 536.98 x 10^5 kg ha−1. The highest maize yield achieved during this period was in 2018 with 536.98 x 10^5 kg ha−1 while the lowest of 312.85 x 10^5 kg ha−1 was recorded in 2000 (Fig. 9). From 2000-2018, the cropland under maize production increased by about two times.

While the land under maize crop production has experienced a significant increase from 2000-2018, the population in the area has nearly doubled from 176 057 to 249 420 people within such a time frame, which has increased food demand. This signifies that maize crop production in the area for past years from 2000 – 2018 was fluctuating and made maize as the major food crop in the area insufficient for the community.

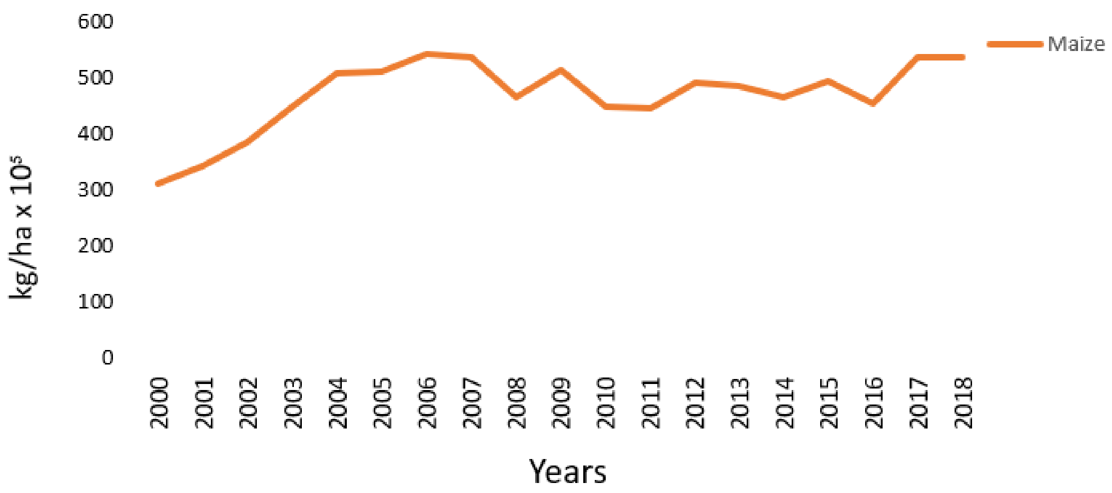

Figure 8: Yields trend of the maize crop-in Serengeti District from 2000 to 2018

4.1.4 Management Cost of *C. odorata* on Maize Production and Yield in Serengeti District

The effects of *C. odorata* on maize plant traits varied among five treatments in the study area. Figure 9 and Table 4 present the performance of maize in a trial treatment T1) No weeding (Control); T2) Weeded throughout (four times); T3) Weeded once; T4) Weeded twice. T5) weeded thrice (Tables 4 and 5). For the number of leaves significant differences were observed ($P<0.05$) in treatment where weeding was done four and three times ($P= 0.012$, $p = 0.011$ respectively), while there was no significant difference in the plot with no weeding, weeding once and weeding twice ($p>0.05$, $p = 0.725$, $p=0.32$ and $p = 0.48$ respectively) for the plant height significant differences was observed in weeding four times, weeding three times and weeding twice times ($P<0.05$, $p = 0.02$, $p = 0.01$ and $p = 0.03$ respectively). In stem diameter, a significant difference was observed in the plot where weeding was done four and three times ($p>0.05$, $p= 0.01$, and $p= 0.014$ respectively). The tallest plant height (190 cm) was obtained in the treatment where a weeding operation was done four times during the maize growing period. The shortest value (169 cm) of plant height was observed in the no-weeding treatment which differs statistically from the values obtained for some of the weeded plots. Weeding four times after planting provided a long stem diameter (18.35 cm) while the lowest stem diameter (9.81cm) was observed in the no weeding treatment. Also, the maximum number of leaves (16) was obtained in the four times weeding treatments while the minimum number of leaves (10) was obtained in no weeding treatment.

Figure 9: Performance of maize with and without *C. odorata* in T1) No weeding T2) weeded throughout; T3) Weeded once; T4) Weeded twice; T5) weeded thrice

Table 4: Maize growth traits performance in five treatments

Treatments	Number of leaves Mean±S.E	Stem diameter (mm) Mean±S.E	Plant height(cm) Mean±S.E	Dry plant weight (kg) Mean±S.E
No weeding	10.77±2.29a	9.81±0.16b	169.07±4.723b	0.06±0.00a
Weeded four times	16.10±0.214b	18.35±0.122c	190.85±3.35c	0.21±0.01b
Weeded once	10.95±0.20a	13.89±2.24a	173.77±2.99b	0.06±0.00a
Weeded twice	12.65±0.17a	12.73±0.24ab	189.67±2.35ab	0.11±0.01b
Weeded thrice	14.35±0.14b	18.55±0.12c	173.77±2.99c	0.17±0.01b

In the table the means within the same column, if followed by the same letter (s), it implies insignificance with P > 0.05 based on Tukey's Honest Significance Difference (HSD) Test. The effects of *C. odorata* on maize productivity differed among five treatments in the study area. Plots whose weeding was done four times exhibited better performance of maize growth parameters and maize grain yield than those which remained without being weeded (Table 5). With regard to the cob weight, the best result was attained on weeding four times treatment after planting (2865.15 kg/ha) (Table 5). However, this treatment was different from the "no weeding" treatment. The poorest grain yield was observed in no weeded plots (520.75) (Table 5). Cob's weight recorded no significant difference in no weeding treatment, weeding once the treatment, and weeding twice treatments (P>0.05, P=1.000, P=0.328, and P= 0.2, respectively). While the significant difference was observed in treatment where weeding was done four and three times (P<0.05, P=0.000, and p=0.001, respectively). In grain yield significant difference was observed in weeding four- and three- times treatment (P<0.05, P=0.014, and P=0.013, respectively). However, there was no significant difference in no weeding treatment and weeding once treatment (P>0.05, P=0.704, and P=0.904), respectively.

Table 5: Grain yield and Cob weight (mean ± S.E.)

Treatments	Grain yield (Kg/plot)	Grain yield (Kg/ha	Cob weight (Kg/plot)	Cob weight (Kg/ha)
T1 No weeding	0.05±0.00a	520.75±57.59b	0.07±0.01c	1272.25±0.00c
T2 Weeded fourth	0.12±0.01b	2403.00±84.26c	0.14±0.01d	2865.15±0.01b
T3 Weeded once	0.05±0.00a	1101.00±93.41ab	0.09±0.00bc	1420.75±0.11c
T4 Weeded twice	0.08±0.00a	1628.75±11.15a	0.10±0.01ab	1927.20±0.03bc
T5 Weeded thrice	0.11±0.01bc	2200.50±203.23c	0.12±0.01d	2357.13±0.01b

The finding observes significant differences (p<0.05) in the MRR among the five different weeding practices on maize production. The MRR was highest in maize which weeded four times *C. odorata during* the growing period. Proper timing and effective control of *C. odorata* on maize farms increased profits. The MRR was significantly greater for the treatment with appropriate and suitable management. From the economic analysis, the increase in maize yield was equivalent to the increase in profit. With weeding four times and three times of C. odorata significant differences were observed on MRR (p< 0.05, p = 0.001, and p = 0.000, respectively). However, there was no significant difference in MRR on no weeding and weeding once treatment ($p > 0.05$, P=0.777 andP=0.459, respectively).

Table 6: Marginal Rate of Return of maize production (/ha, mean ± S.E)

Treatments	TVC (USD)	Grain yield Kg/ha	MRR (USD)
No weeding	240.3	520.75±57.59b	-17.72±14.97c
Weeded four times	296.9	2403.00±84.26c	374.08±22.00d
Weeded once	254.3	1101.00±93.41ab	51.16±24.28bc
Weeded twice	268.5	1628.75±11.15a	183.17±28.90ab
Weeded thrice	282.9	2200.50±203.23c	312.63±52.84d

4.2 Discussion

4.2.1 Distribution of *C. odorata* in Western Serengeti

Results indicate that roadside, agriculture, and pasture lands had the highest distribution of *C. odorata* population. This study shows that the richness and abundance of invasive weed *C. odorata* are the results of an interaction between diverse factors including abiotic environment and non- climatic factors such as, it has a competitive ability with other vegetation, one mature plant can produce roughly 1 million seeds per year, which enables rapid spread and the establishment of large populations over a relatively short period and Its ability to form dense, impenetrable thickets leads to the displacement of native plant species (Pyšek *et al.*, 2012). According to Van *et al.* (2017), the Serengeti area is climatic and more prone to invasion of *C. odorata* which enables the weed to establish and become more invasive in this area following its introduction. The rate and extent of spread of *C. odorata* since its introduction have been noticeable in many areas of Serengeti, including agricultural lands, grazing land, and villages. Soil is also another factor accounting for the distribution of *C. odorata* in Serengeti. The soil in Serengeti seems most suitable for invasion of *C. odorata* and this argument is in line with the findings by Mandal and Joshi (2014). Thus, the conclusion from these findings is that the distribution of *C. odorata* in Serengeti is mainly an outcome of climatic and non-climatic factors. Thus, there is a likelihood of a continuing increase in the distribution of *C. odorata* in the future in the absence of effective management interventions.

4.2.2 Maize Crop Production Trends in Relation to Climate in Western Serengeti

The agricultural sector is the overriding economic sector in Tanzania and covers over half of the GDP and export earnings (Vermeulen *et al*., 2012). The livelihood of more than 80% of people in rural settings depends on agriculture. Agriculture performance is, therefore, an important factor in determining livelihood prospects. According to the URT (2003), total maize production was 1.2 tons/ha, which is below the 1.38tons/ha in the lake zone, and far below the potential maize production of 4tons/ha. Compared to the 2003 national agriculture census, there is an increase in area planted with maize from 2003-2018. Although the available area planted with maize is consistently increasing, as well as increasing yield, according to the 2003 report, 58% of households did experiences food deficient problems at a different level from severe to mild.

The impacts of climate change on agriculture may add significantly to the development challenges of ensuring food security and reducing poverty. The growing period means the annual temperature for maize ranges from 23 °C to 25.91 °C (Cofas, 2018). Temperature drives the physiological and morphological development of the maize plant, with each process requiring a different minimum and maximum temperature. The mean annual temperature of the study area in maize growing seasons seems to be crucial for the early establishment and growth of the seedlings which ultimately influences the yield. Climate change predictions for SSA have changed from earlier studies which gave values of 1.6 ◦C to recent projections of above 2.4 ◦C by 2050, depending on emissions and other anthropogenic activities. Increasing trends in mean annual temperatures are predicted for SSA, and extreme climate events, especially the frequency and severity could negatively impact yields (Lobell *et al.,* 2011). Maize yield in Serengeti District will be most vulnerable to water stress if the mean annual temperature will increase. During the entire growing period from 2000 to 2018, the mean annual temperature varied. This study showed the annual mean temperature was currently low for optimal growth, an increase in these temperatures will increase yield but an overall increase in temperatures over time can negatively impact yield. Rainfall requirements of maize vary depending on the agro-ecological zones, it performs optimally in regions that receive an annual rainfall of 600–1000 mm (Durodola & Mourad, 2020). Based on the study mean annual rainfall which varied from 700 mm to 1300 mm, was enough than the optimum value. This implies that other factors besides rainfall and temperatures may be utilized to explain the variation in maize yield. Thus, maize yield was not just a product of climatic variables, but also a combination of other agronomic factors.

Also, over the next three decades, agricultural areas are expected to experience a farming season that is likely to have higher temperatures than the current situation, exacerbating the current invasions and facilitating the new ones (Pyšek *et al.,* 2020). Crop production is expected to be affected in various ways. For example, invasion from invasive weeds on maize crop, which comprises the top 75% of the total value of agricultural output for most countries in the world (including Tanzania), is likely to be significant in the future, given that most of its areas are already infested with invasive pests and pathogens. Similarly, the Sub-Saharan African agricultural sector is at risk of the invasive weed, resulting in lower productivity (Pimentel *et al.,* 2001; Simberloff *et al.,* 2013).

4.2.3 Performance of Maize, Management Cost, and Yield as Influenced by *C. odorata* Invasion Weed

Invasive weeds present substantial threats to agriculture, with varying magnitude and distribution of the threats between countries (Paini *et al.*, 2016). Invasive weeds have caused a severe reduction in agricultural communities' food production, leading to loss of income and increased livelihoods vulnerability (Pratt *et al.,* 2017; Shackleton *et al*., 2019). Smallholder farmers will need the relevant, cost-effective adaptive strategies that they can use to get the optimal crop yield from their invaded land to meet future challenges. Some of these strategies can be found within the traditional and indigenous agronomic management practices, commonly used by farmers in different crop production approaches as implemented in the invaded agricultural land.

Indigenous communities rely extensively on knowledge and networks, such as crop production management practices, which have significantly enhanced their livelihoods and economies, thus promoting the survival and persistence of its individuals and their resources (Cámara-Leret *et al.,* 2019). Their knowledge and practices are crucial to breeding determinations to adjust agriculture to climate change (Guarino & Lobell, 2011). Recently, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has acknowledged the need to include in scientific assessments and policy the unexplored role that culture plays in improving the beneficial contributions of nature to people (Díaz *et al*., 2018; Isbell *et al*., 2017). This recognition acts as a wake-up call for understanding and tapping opportunities inherent in communities to address the problems and challenges they face in engaging themselves in day-to-day livelihood activities, such as agricultural production.

Findings from this study indicate a negative (competitive) species interaction, which occurs when one species exerts a negative effect on the other species due to competition for resources such as light, nutrients, and moisture. One of the most noticeable impacts of invasive weeds is the direct loss of crops due to infestations (Perrault *et al.*, 2003). The maize crop is vulnerable to competition from invasive weeds, and such competition may even lead to crop failure. The longer the invasive weeds remain in competition with the crop, the greater the damage to the crop. The significant reduction in maize growth parameters, plant height, stem diameter, number of leaves, and change in maize color from greenish to yellow *C. odorata* was due to nutrients uptake by invasive weed.

High growth ability and the spreading of *C. odorata* have induced vertical competition for space to maize which might also be a reason for low plant height in plots with more competition duration (Saeed *et al.,* 2010).

A decrease in grain weight per cob in plots with extension in the invasion period led to more competition for nutrients and space, especially at the flowering and fertilization stage, where significant differences were noticed, such as a change in leaves' color from green to yellow, slow growth. The number of grains in weed invasion-free treatment was enhanced compared with weedy conditions. Tanveer *et al*. (2018) observed that the invasion at early growth stages of maize causes a reduction in final maize grain yield, with more yield losses occurring at treatment with a long invasion weed competition period. The steady reduction in maize yield with increasing weedy duration was likely an outcome of a decrease in the major yield traits, as noted in this study. Gantoli *et al.* (2013) observed that weed infestation in maize for 7 weeks after planting caused a 24% reduction in maize yield compared to weed-free. In another study, Gholami (2014) recorded a significant decrease in the yield of maize when employed to weed infestation up to 5 weeks after planting.

The study showed that 15 to 45 days after planting was the critical period for *C. odorata* competition on maize crops. This competition ability might be due to the strong allelopathy potential of this weed with maize crop (Muzzo *et al*., 2018). High nutrient uptake of *C. odorata* compared to other weeds might also be among the major reasons for high competition. Maqbool *et al.* (2006) reported a decrease in the yield of maize as weed and crop interface duration with the crop was increased from 15 to 60 days after planting. Furthermore, the maximum grain yield decline of up to 51% was noted in plots with weed-crop competition for the entire cropping season. Safdar *et al.* (2016) found that the critical time for weed removal could be from 15 to 30 days after planting to avoid yield losses of 5% in maize. This study recorded a high reduction in maize grain yield with *C. odorata* duration ranging from 15 to 30 days after planting during the growing season. Thus, understanding weed competition duration on crop yield is important to develop an effective weed management plan to ensure effective, economical, and eco-friendly weed control.

The study indicates that four weeding after planting must be carried out for a greater maize yield in the study area. The competition between *C. odorata* weed and maize was too adverse on no weeding area at all and that weed was done once during the growing period. However further significant increases in the maize grain yield and reduction in yield were minimized in the plot where weeding was done four times.

4.2.4 Estimated Profits and Marginal Rates of Return

The MRR was highest in an area where *C. odorata* was weeded four times compared to the area where there was weeding of *C. odorata* with plots infested with *C. odorata* at different levels. Proper timing and effective control of *C. odorata* on maize farms increased profits. From the economic analysis, the increase in grain yield with weeding four times of *C. odorata* translated into significantly higher MRR and dollar profit for maize farmers in the Serengeti district in northern Tanzania. There was an addition of 1411 Kg. ha^{-1} grain yield, equivalent to a 70% increase in dollar profit, with the absence of invasive weeds *C. odorata* on maize production in the Serengeti area. These results indicate that maize production is profitable. This result is in line with the findings of Olaniyan and Lucas (2004). The result also shows that labor costs constituted a greater proportion of the costs incurred in the maize production process by the farmers.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Despite our familiarity with climate change's effects on crop production, more information is required on the crop output patterns as a function of rainfall and temperature. This study demonstrates that rainfall and temperature had a constant association with maize. This study highlights that the rainfall and temperature in the study area are not the major factors that dramatically affect the yield of maize. Similarly, the study shows that roadside, agricultural and pasture lands have the highest distribution of the *C. odorata* population. Also, the study concludes that concluded that the lack of *C. odorata* control on maize production reduces grain yield and its components. The highest yields were obtained with four weeding times also the greater Marginal return rate of the maize production was obtained when *C. odorata* weeding was conducted four times after maize plantation. Moreover, the study shows that the priority to help individual smallholder farmers grow maize in the Serengeti district to control *C. odorata* should be done weeding four times for management of *C. odorata* on their cropland. National policies and decision-making bodies and international donors should therefore integrate locally-relevant, effective, and evidence-based information into targeted investments in weed management strategies for *C. odorata*, to farmers to reduce infestation and improve maize yield.

5.2 Recommendations

(i) Since the science of climate impacts is dynamic, this study calls for further investments in studies that detail information on climate change and adaptation in Serengeti and other parts of the country.

(ii) Weeding of *C. odorata* four times during the maize growing period will help to increase the yield of maize and make available to smallholder farmers the underutilized and abandoned cropland areas that *C. odorata* have infested.

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RESEARCH OUTPUT

Journal Paper

Makere, M. E., Munishi, L. K., & Ndakidemi, P. A. (2021). Effectiveness of management (coping) strategies for Chromolaena odorata by smallholder farmers in Serengeti District, Tanzania. *Journal of Biodiversity and Environmental Sciences, 19*(2), 13-21.

Poster Presentation

Poster Presentation

IMPACT OF CLIMATE CHANGE AND MANAGEMENT COST OF *Chromolaena odorata* ON MAIZE PRODUCTION FOR SMALLHOLDER FARMERS IN SERENGETI DISTRICT, TANZANIA

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Introduction

- Crop production worldwide have been influenced by several factors including low soil fertility, water, climate, pest, and diseases
- Both climate change and invasive weeds present serious threats to the agriculture sector by increasing economic costs and reduction of crop yield
- Recently deadliest invasive weed *C. odorata* has been a problem in Serengeti District including its colonization of cropland
- Thus, there is a need to carry out a scientific study to understand the extent to of weeds and climate change themselves affect crop production in small-scale fields, and what should be done to address the problem.

Objectives

- To map the current areas invaded by *C. odorata* in Serengeti District, Tanzania
- To assess maize production patterns in relation to climate change in the Serengeti District.
- To establish the management costs and yield between non-infested and infested croplands with varying intensities of *C. odorata* in Serengeti cropland.

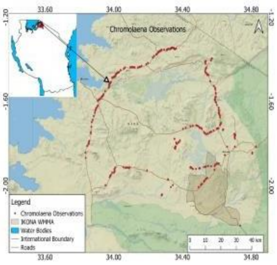
Methodology

- Road transects and observation of *C. odorata* on cropland
- GPS points recording
- Maize crop production data documented from 2000-2018 from Serengeti District Authority, Climate data from Grummet Game reserve analyses using Person's correlation
- Experimental Field trial in Serengeti cropland

Results and Discussions

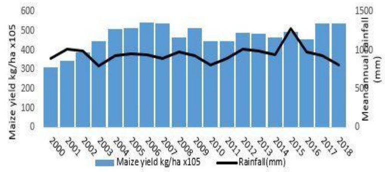
Distribution

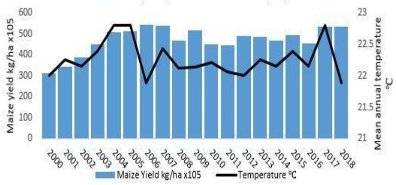
- Total of 340 were collected
- More distribution of *C. odorata* were observed in abandoned cropland, roadside and adjacent area near Serengeti District



Climate and maize production

- Climate shows positive correlation with maize production in Serengeti District
- This implies that other factors besides rainfall and temperatures





Maize yield and Marginal return rate

- Good performance and yield of maize observed in the area weeding of *C. odorata* were done four times during the growing period
- 2403 Kg. ha^{-1} of maize grain yield equivalent to a 70% increase Marginal return rate observed in area weeding was done four times.

Recommendations

- Since the science of climate impacts is dynamic, study calls for further research that detail information on climate change and adaptation in Serengeti.
- Cost- effective strategies for management of *C. odorata.*

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