

**INFLUENCE OF WEED CONTROL OPTIONS ON GROWTH AND YIELD OF
CASSAVA IN EASTERN ZONE OF TANZANIA**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE
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EXTENDED ABSTRACT

Cassava (*Manihot esculenta* Crantz) is an important crop in sub-Saharan Africa as it has been used as staple food by most of tropical Africans, it is averaged to be used as food on over 24 countries in Tropical Africa. Despite of the importance of cassava as food and cash crop in Tanzania, its production is affected by several factors, weed being one of those and it has been estimated that weed reduce cassava yields by almost fifty percent. In the Eastern zone of Tanzania, adoption of the best integrated weed control options on cassava production has not been clearly done, thus farmers still face challenges in terms of efficiency, timeliness and effectiveness in weed control as they mostly relay on a single weed control option. Also, weed control cost has been very high leading to inappropriate weed control as it has been estimated that the annual cost of weed control been almost \$ 4.3 billion in Africa. This study aimed at developing the best integrated weed control combination for improved cassava productivity. Specifically, the study sought to: (1) to identify common weeds found in the selected cassava farms in Eastern zone of Tanzania, (2) to determine the effect of tillage, pre-emergence and post-emergence weed control options on weed growth, cassava yield and soil quality and (3) to conduct cost benefit analysis of the selected weed control options in cassava farms. The first chapter contain general introduction, the second, third and fourth in the dissertation comprise manuscripts in the form of publishable papers which cover the first, second and third specific objectives while chapter five covers general conclusion and recommendations.

The effects of different weed control treatment combinations were studied during the 2019/2020 planting season at Ilonga village, Kilosa district and Kiimbwanindi village, Mkuranga district. For the first objective, a study was carried out from November 2019 to April 2020 in which a field survey was done to identify common weeds found in cassava

fields in two sites. A total of 24 random 1 m × 1 m quadrat were placed in each cassava field whereby all weed species found in each quadrat were identified to a species level. During weed identification, weed density, uniformity and frequency were calculated according to Thomas methodology and used to determine relative abundance. The effect of different weed control treatment combinations on weed growth and cassava yield, soil quality and cassava profitability were studied for the objectives two and three, respectively. Till only and till + Ridge, pre-emergence herbicides (Primagram Gold a.i 290 g/L S-metolachlor + 370 g/L atrazine and Oxfen a.i Oxyfluorfen 24% EC), post emergence herbicides (Force up a.i 480 g/L of Glyphosate-Isopropylamine salt and back pack weeder with modified tines) were tested on Cassava variety Kiroba in a factorial experiment arranged in a randomized complete block design (RCBD) replicated three times. Data on the number of days for the weed reemergence, cassava plant height and cassava stem girth at five months after planting, cassava fresh root weight, cassava biomass and cassava dry matter content were collected. Also, a random composite soil samples were collected from each field at a depth of 0-30 cm before land preparation and after harvesting, and analyzed in the laboratory to determine the soil pH, total N, P, K, Ca and Mg nutrients content. Data obtained were subjected to analysis of variance (ANOVA) at $P \leq 0.05$ using R statistical package version 3.5.2. The treatment means were compared using Tukey's honestly significance test at alpha 5% for objective two. For the objective three, data collected were all variable costs for the inputs applied on each weed control treatment combination, costs of cassava harvesting and the price of cassava per kilogram, and data were subjected to benefit-cost ratio analysis.

Results revealed that, there were 22 weeds species belonging to 16 families identified in the cassava fields, whereby out of those species, 14 were broad leaved weeds, 6 grassy weeds, 1 sedged weed and 1 mushroom belonging to 10 perennial and 12 annual weed

plants. During weed identification, *Cyperus rotundus* and *Echinochloa colona* were the most abundantly weed species while *Dactyloctenium aegyptium*, *Portulaca oleracea*, *Agaricus sp* and *Bidens pilosa* were the least abundant weed species at both sites. Results showed, a combination of tillage practices and pre-emergence herbicides application (S-metolachlor + atrazine at 3.0 lts a.i/ha and Oxyfluorfen at 3.0 lts a.i/ha) increased number of days weeds took to emerge in both sites. Also, the correlation analysis showed a non-significant positive relationship, $r = 0.389$, $p > 0.05$ and $r = 0.055$, $p > 0.05$ between cassava stem height and cassava fresh root weight, and cassava stem girth and cassava fresh root weight, respectively at Kiimbwanindi site and highly significant strong positive relationship, $r = 0.925$, $p < 0.001$ and $r = 0.781$, $p < 0.05$ between cassava stem height and cassava fresh root weight, and cassava stem girth and cassava fresh root weight, respectively at Ilonga site. Combination of weed control treatments significantly affected cassava fresh root weight and biomass, ($p = 0.019$ and $p = 0.026$, respectively) at Kiimbwanindi while at Ilonga, combination of weed control treatments did not significantly affected the cassava fresh root weight, ($p = 0.514$) and cassava biomass ($p = 0.732$). Further findings indicated that, the selected weed control treatment combinations had not significantly affected soil pH, amount of total N, P, K, Ca and Mg nutrients at Ilonga and Kiimbwanindi sites. The highest profit at Kiimbwanindi site was recorded on till \times Oxfen \times Force up and till \times Primagram \times Force up treatment combinations which had the benefit cost ratio of 2.39 and 2.04, respectively while at Ilonga site, only Till and Rigde \times Oxfen \times Force up treatment combination had the benefit cost ratio of 2.31 and high cassava root yield of 25.58 t ha⁻¹.

We conclude that, perennial weeds *Cyperus rotundus*, *Echinochloa colona*, *Trichodesma zeylanicum*, *Reissantia sp*, *Mucuna pruriens* and *Commelina benghalensis* were the most and abundant occurred weed species due to their ability to adapt into various soil types

and their ability to reproduce as compared to other weeds. The combination of till + ridges, application of pre-emergence herbicide (S-metolachlor + atrazine) and post emergence herbicides (glyphosate) provided favorable environment for cassava growth and root formation as compared to other treatment combinations. Also, these results proved that, proper use of weed control methods have had minimum effects on the soil quality while having positive impacts on the cassava performance. However, its recommended that, for the positive nutrient balance in cassava production, it is important to apply fertilizers that contain high N and K nutrients because cassava responds effectively on these nutrients. Also, good farm preparation, the use of *Oxyfluorfen 24% EC* herbicides as pre-emergence herbicide and *480 g/L of Glyphosate-Isopropylamine salt* as post emergence weed control treatments should be encouraged in cassava production as they lead to maximum profit.

For maximum cassava productivity, proper tillage and ridging before cassava planting, use of pre-emergence herbicide made of S-metolachlor and atrazine and proper use of glyphosate as post emergence herbicide could highly help keeping cassava farms free from weed for a longer period of time as compared to other treatment combinations. Also, more research is recommended on a regular basis to identify possible weed population shifts for improved control measures needed.

DECLARATION

I, Leonard, Joseph Adonia, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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The above declaration is confirmed by;

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LIST OF ABBREVIATIONS AND SYMBOLS

\$	United States Dollar
%	Percentage
°C	Degree centigrade
a.i	Active ingredient
ACAI	African Cassava Agronomy Initiative
ANOVA	Analysis of Variance
ASL	Above sea level
BCR	Benefit-Cost ratio
Ca	Calcium
CBA	Cost-benefit analysis
Cm	Centimeter
Cu	Copper
CV	Coefficient of variation
E	East
EC	Emulsifiable concentrate
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
Fe	Iron
g/L	Grams per liter
GPS	Global Positioning System
H ₂ O	Water
Ha	Hectare
IITA	International Institute of Tropical Agriculture
K	Potassium
LS	Loamy sand soil

lts	Liters
M	Meters
MAP	Months After Planting
Mm	Millimeter
Mn	Manganese
MR	Marginal return
N	Nitrogen
Na	Sodium
P	Phosphorous
p	P-value
PEWC	Post emergence weed control
Ppm	Parts per million
RA	Relative abundance
RCBD	Randomized complete block design
RCO	Regional Commissioner's Office
S	Sulfur
SCL	Silty clay loam soil
SL	Sandy loam soil
Sp	Species
tha ⁻¹	Tones per Hectare
TR	Total revenue
TVC	Total variable cost
WAP	Weeks After Planting
Zn	Zinc

CHAPTER ONE

1.0 INTRODUCTION, JUSTIFICATION AND OBJECTIVES

1.1 Introduction

Cassava (*Manihot esculenta* Crantz) is an important crop in Sub-Saharan Africa as it has been used as staple food over 24 countries in Tropical Africa (Tonukari, 2004; Nhassico *et al.*, 2008). Tanzania is the sixth largest producer of cassava in Africa after Nigeria, the Democratic Republic of Congo, Ghana, Angola and Mozambique, producing almost 7 million tons of fresh cassava roots annually, with an average yield of 10 tons per hectare (Nweke, 2004). Due to its high demand, global cassava production has increased over the years particularly from Sub-Saharan Africa. According to FAOSTAT (2016), in 2007, world production had reached 228 million metric tons, with Africa accounting for more than 53%, Asia for 30% and Latin America and the Caribbean for 17% of the total. Cassava ranks very high among crops that convert the greatest amount of solar energy into soluble carbohydrates per unit area (Tonukari, 2004). Among the starchy staples, cassava gives a carbohydrate production which is about 40% higher than rice and 25% more than maize, as a result cassava becomes the cheapest source of calories for both human nutrition and animal feeding. Also, cassava has great potential to spur industrialization, improve household food security, increase incomes, generate employment, and reduces poverty (Abass *et al.*, 2018).

1.1.1 Weed management in cassava production

Despite of its importance, cassava is highly susceptible to weed infestation. The susceptibility of cassava to weed infestation has been reported to be caused by its slow initial growth rate, wide plant spacing and its long maturity period of between 12 and 18 months (Chikoye *et al.*, 2001; Howeler, 2007; Ekeleme *et al.*, 2019). Different researches

reported that cassava have been very susceptible to perennial weed species such as *Imperata cylindrica*, *Chromolaena odorata*, *Panicum maximum*, *Cyperus rotundus*, and *Mimosa invisa* which if not properly managed may cause cassava root yield losses of about 40% to 90% depending on the severity of the infestation (Baron, 2005; Islami *et al.*, 2017; Ekeleme *et al.*, 2019).

1.1.2 Weed management practices

Weed control within the first eight to sixteen weeks after cassava planting is critical in order to avoid yield loss. Schwartz-Lazaro and Copes (2019) indicated that proper soil tillage is the one of the first and far most weed control method used to expose weed seeds to the unfavorable conditions for their germination while improving soil aeration, soil porosity and improves root penetration. However, Figueiredo *et al.* (2017) reported excessive tillage may lead to soil erosion and rapid nutrient depletion due to leaching. The other method of weed control is the used of herbicides, which can be pre-emergence herbicides which are applied in the soil soon after planting and they do control weeds as seeds germinate and reducing early-season weed competition, others are post-emergence herbicides whose applications target weed species not controlled by soil applications, these herbicides can either control weeds emerging at the time of application or already emerged weeds and provide residual activity against later emerging weeds (Kraehmer *et al.*, 2014; Ekeleme *et al.*, 2016; Schwartz-Lazaro and Copes, 2019). Westwood *et al.* (2018) reported that, proper use of herbicides helps in improving soil quality and reduced soil erosion as the result of the weed debris remained in the soil while Islami *et al.* (2017), reported that, improper use of herbicide can lead to soil degradation and evolution of resistant weeds.

1.1.3 Effects of weed control options on soil quality in cassava production

Continuous land preparation and weeding using hand hoe is one of the major causes of soil loss as it exposes the soil to sun, wind and runoff which erode the top soil thus loss of soil fertility (Islami *et al.*, 2017; Sims *et al.*, 2018). Also, long term and excessive use of chemicals in controlling weeds lowers the soil organic matter content as compared to the use of mechanical weed control options (Islami *et al.*, 2017). Thus, the adoption of proper integrated weed control options may help in improving the soil quality and reduce soil erosion (Gianessi and Williams, 2016; Islami *et al.*, 2017).

1.1.4 Effects of weeds on soil quality

Presence of weeds in a cassava farm may alters the soil ecosystem and crop-weed interaction as weeds are often perceived to exerting negative effects on crop growth as it reduces the soil nutrients (Smith *et al.*, 2011). Plant's nitrogen (N) uptake efficiency has been shown to be influenced by tillage, soil properties, interactions among crops and weeds and the rate and source of N applied. Competition for N between crops and weeds can result in reduced available N for uptake and utilization by the crop, impacting crop yield (Knezevic *et al.*, 2002; Knight *et al.*, 2017). Also, studies show Phosphorus fertilization in soil significantly increased the number of weed seedlings, but Potassium fertilization had no effect on weed emergence (Freyman *et al.*, 1989). Bauer and Black, (1994) reported the competitive interactions between weeds and crops can be manipulated by altering nutrient pools and the quantity and quality of organic matter as organic matter is the major indigenous source of soil available N, total soil P and provides significant amounts of S and other nutrients essential for plant growth. Also weed diversity influences the composition and functioning of the soil microbial community, including the abundance of pathogenic and beneficial microorganisms (Wolfe and Klironomos, 2005; Smith *et al.*, 2011).

1.1.5 Cost-benefit on weed control options/economics of weed control options

In cassava production, the choice of weed control method(s) to use depends not only on its efficacy but also on its cost. It has been reported by Rana and Rana (2016), that weeding activities take 50 to 80 percent of the total cassava production budget. Thus, weeds should be controlled by least expensive available method(s) that will effectively control weeds while not interfering with other phases of cassava production (Rana and Rana, 2016; Ekeleme *et al.*, 2019). In order to determine the most feasible integrated weed control option(s), there must be a good choice of the inputs to be used, their cost of operation and output obtained (Rana and Rana, 2016). This can be done by analyzing the benefit cost ratio of the input used and if the ratio obtained is above the threshold which is one means that, the farmer would get more additional returns from investment thus the cost of operation is much lower than the profit that farmer will get from his/her investment.

1.2 Justification

Despite of the cassava importance as food and cash crop in Tanzania, its production is affected by several factors, weed being one of those. It has been estimated that weed reduce cassava yields by almost half (Islami *et al.*, 2017).

The adoption of the best integrated weed control options on cassava production has not been effectively done, thus farmers still face challenges in terms of efficiency, timeliness and effectiveness in weed control as they mostly rely on a single weed control option (Kayeke *et al.*, 2018). Also, weed control cost has been very high leading to inappropriate weed control. According to Kayeke *et al.*, (2018), the annual cost of weed control has been estimated to be \$ 4.3 billion in Africa, and this cost has been a huge burden to farmers.

Several efforts have been made since mid-1980s by the Tanzanian National Root Crop Research Program and International Organizations including breeding of new varieties with acceptable agronomic qualities in order to increase cassava production but with little success in controlling weed (Nweke *et al.*, 1998). Various weed control studies concentrated on a single weed control method (Santiago *et al.*, 2018). The use of herbicide has been found to improve soil quality and reduce cost of weeding (Islami *et al.*, 2017), while mechanical weeder was found to reduce time of weeding, cost and it is efficiency in controlling weeds (Ekeleme *et al.*, 2016). Tillage expose weed seed and underground structure to weed control options (Sims *et al.*, 2018).

However, the efficiency of these technologies depends on weed species, climatic conditions, and soil characteristics (Ekeleme *et al.*, 2016). Therefore, the study aimed at identifying the most common weed species in selected cassava farms of the Eastern Tanzania, determining the efficiency of selected weed management strategies and effect of tillage on weed control and soil quality improvement, and the cost benefit analysis on integrated weed management options to optimize soil quality and cassava productivity.

1.3 Objectives

1.3.1 Overall objective

Developing the best integrated weed control options for improved cassava production and productivity.

1.3.2 Specific objectives

- i. To identify common weeds found in the selected cassava farms in Eastern zone of Tanzania.
- ii. To determine the effect of tillage, pre-emergence and post-emergence weed control options on weed growth, cassava yield and soil quality.
- iii. To conduct cost benefit analysis of the selected weed control options in cassava farms.

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CHAPTER TWO

2.0 COMMON WEEDS FOUND IN SELECTED CASSAVA FARMS IN THE EASTERN ZONE OF TANZANIA.

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2.1 Abstract

A field study was conducted at Ilonga village, Kilosa, Morogoro region and Kiimbwanindi village, Mkuranga district, Coast region to identify the common weeds affecting cassava in the fields. A total of 24 random 1 m × 1 m quadrats were placed in each cassava field whereby weed species found in each quadrat were identified to a species level. During weed identification, weed density, uniformity and frequency were calculated according to Thomas procedure and used to determine relative abundance. Also, composite soil samples were collected based on random sampling procedure at a depth of 0 to 50 cm from each field before land preparation for laboratory analysis to determine the nutrient status of the soil.

A total of 22 weeds species belonging to 16 families were identified, whereby out of these 14 were broad leaved weeds, 6 grassy weeds, 1 mushroom and 1 sedged weed belonging to 10 perennial and 12 annual weed plants. During weed identification, *Cyperus rotundus* and *Echinochloa colona* were the most abundantly occurred weed species while *Dactyloctenium aegyptium*, *Portulaca oleracea*, *Agaricus sp* and *Bidens pilosa* were the least occurred weed species.

Perennial weeds *Cyperus rotundus*, *Echinochloa colona*, *Trichodesma zeylanicum*, *Reissantia sp*, *Mucuna pruriens* and *Commelina benghalensis* were found to be the most

and abundant occurring weed species. The study recommends that, more research work is needed on a regular basis to identify possible weed population shifts for development of new or improved weed control measures that may be needed.

Keywords: *Weed, Thomas methodology, Relative Abundance and Weed density*

2.2 Introduction

Weed is any plant that originate in a natural environment and in response to imposed or natural environments evolved, and continues to do so, as an interfering associate with crops of interest and its activities. Weeds can also be defined as the plants, which grow where they are not wanted that is objectionable or interferes with the activities or welfare of man (Conrad *et al.*, 2018). The interference of weeds in the farm, they interface with the utilization of natural resources, harmful, dangerous, prolific, persistent, resistant, competitive, even poisonous, and economically detrimental and can grow under adverse climatic conditions (Rana and Rana, 2016).

Weeds are characterized by having long seed life in soil, quick in emergence, have ability to survive and prosper under the disturbed conditions of a cropped field, have rapid early growth and do not have any special environmental requirements for their seeds to germinate. Example Rana and Rana (2016), explained that *Cyperus rotundus* which have 78% viability can propagate through tubers. Weeds can be classified using taxonomic (scientific identification method) whereby there are at least 450 families of flowering plants and over 350 000 different species, in which only about 3 000 of them are used by humans for food. Fewer than 300 species have been domesticated, and of these, there are about 20 that stand between humans and starvation. Other classification methods used are based on life history, habitat, morphology, or plant type (Rana and Rana, 2016).

Cassava is highly susceptible to weed infestation especially from perennial weeds. This is because of its initial slow growth rate, wide plant spacing, and the long maturity period of between 12 and 18 months (Chikoye *et al.*, 2001; Howeler, 2007; Ekeleme *et al.*, 2019). According to Olorunmaiye *et al.* (2013) cited by Ekeleme *et al.* (2019), environments where cassava is growing tend to be dominated by perennial weed species such as

Imperata cylindrica, *Chromolaena odorata*, *Panicum maximum*, *Cyperus rotundus*, and *Mimosa invisa* which if not properly managed may lead to cassava root yield losses of about 40% to 90%.

In Africa, the annual cost of weed control is estimated to be \$ 4.3 billion (Kayeke *et al.*, 2018). Also, Rana and Rana (2016) and Ekeleme *et al.* (2019), reports indicated that, in cassava production, weeding activities take 50 to 80 percent of the total cassava production budget. This is mainly because weeds vary not only in their ability to compete with crops and reduce yields but also vary in their response to different management strategies. Therefore, proper and accurate weed identification (information on weed species diversity, frequency of occurrence, competitive ability and abundance) is the first step to successfully management of weeds especially using improved technologies (Baron, 2005; Ekeleme *et al.*, 2019).

2.3 Materials and Methods

2.3.1 Description of the study sites

The study was conducted in the Eastern zone of Tanzania where by two fields were selected, one at Ilonga village, Kilosa district, Morogoro region (6°46' 27" S, 37°2'14" E, and 479.95 masl) and another at Kiimbwanindi village, Mkuranga district, Coastal region (7°12'19" S, 39°20'38" E, 93.87 masl). Average monthly temperature in Mkuranga range from 18.8 °C during July and August to 31.9 °C to 32.6 °C in the hottest season of December to March (Mkuranga, 2009; RCO, 2011). Relative humidity ranges from 67-70 % from August to October, increasing to 82 % in the wettest months of April. The average annual rainfall is 1,073 mm (ranging from 585 mm to 1,536 mm). Mkuranga experiences a bi-modal rainfall pattern where long rain start in March ending in May with

about 550 mm of rain and short rains starting in November ending in January with 235 mm of rain (Mkuranga, 2009; RCO, 2011).

In Kilosa, the district experiences an average of eight months of rainfall (October to May), with the highest levels between February and March. The rainfall distribution is weakly bimodal in good years, with short rains starting in October ending in January, followed by long rains starting in mid-February ending in May. Mean annual rainfall ranges between 1 000 and 1 400 mm in the southern flood plain, while further north (Gairo Division) has an annual rainfall ranging from 800 to 1 100 mm. The mean annual temperature in Kilosa is about 25°C (Kajembe *et al.*, 2013; Zakayo, 2015).

2.3.2 Weed sampling procedure

A field survey of weeds in the selected cassava fields of 861 square meters each at Ilonga and Kiimbwanindi was conducted between November 2019 and April 2020. The selection of the fields in Eastern zone of Tanzania was based on the frequency of cassava production and productivity on those areas. A total of 24 quadrats (1 m × 1 m) were placed at random in each selected cassava field, where the distance from one quadrat to the other was ten meters. In each quadrat all available weed species were identified and classified to a species level, counted and recorded as per Moeini *et al.* (2008) procedure. Clear pictures of these weeds (including those weeds found out of the quadrats) were taken for records. The position of each field sampled was recorded using a Global Positioning System (GPS) whereby the information on history of cultivation, methods of land preparation, fertilizer application, troublesome and most challenging weeds and weed management practices were also collected.

2.3.3 Data collection

Data collected included weed species, density, frequency, uniformity and relative abundance. Other data collected were geo-positions and soil characteristics. Both physical and chemical soil characteristics were analyzed at IITA soil laboratory in Dar es Salaam to assess fertility status and their suitability for cassava production. These data were helpful in proper weed identification and in the study of the best weed management options.

2.3.4 Data analysis

For the determination of relative abundance (RA) of each weed species in the Thomas method, five quantification measures were used, these were weed frequency, relative frequency, uniformity, relative uniformity, and mean field density (Thomas, 1985). The soil characteristics were analyzed in the laboratory following procedures by Jones (2012) and the methods used are presented on table 2.1 below. The following are procedures and formulae used to determine the RA in Thomas methodology (Thomas, 1985).

2.3.4.1 Weed density of each species was obtained by taking the number of real plants in each field/quadrat divide by the number of fields/quadrats. Thus

$$D_{ki} = \frac{\sum z_j}{n} \quad (i)$$

Whereby

D_{ki} = density (number of plants or spikes/panicles/m²) of the species k in field i

Z_j = number of plants/spikes/panicles in each 1m² sample

n = number of fields

2.3.4.2 Weed frequency of each species was obtained by taking the ratio of the number of fields where the species was present, to the total number of fields. Thus

$$F_k = \frac{\sum Y_i}{n} \times 100 \quad (\text{ii})$$

Whereby

F_k = frequency of the species k

Y_i = present (1) or absence (0) of the species k in the field i

n = number of fields

2.3.4.3 Weed uniformity indicates the percentage of quadrats infested by a species and is an estimate of the area infested by a weed. Thus

$$U_k = \frac{\sum \sum X_{ij}}{m} \times 100 \quad (\text{iii})$$

Whereby

U_k = field uniformity value for species k,

X_{ij} = presence (1) or absence (0) of species k in quadrat j in field i, and

m = number of quadrats per field.

2.3.4.4 Relative abundance is the overall evaluation of the importance of each species with respect to others, and the RA of each weed species was obtained by the formula

$$RA_k = RF_k + RU_k + RD_k \quad (\text{iv})$$

Whereby

RA_k = the relative abundance of species k

RF_k = (the frequency of species k / sum of all frequencies of all species) \times 100

RU_k = (uniformity of species k / sum of all uniformity values of all species) \times 100

RD_k = mean density of species k / sum of mean field densities of all species) \times 100

2.4 Results

2.4.1 Physical and chemical characteristics of the soils at study sites

Soil chemical characteristics and particle size distribution at two depth 0 to 20 cm and 21 to 50 cm deep at experimental sites in 2019 are shown in Table 2.1. The soil texture for the two sites were silty clay loam (24% clay, 15% silt and 61% sand) with sufficient available phosphorus, total nitrogen and exchangeable potassium and the pH of 5.88 at Ilonga and loamy sand (12% clay, 3% silt and 85% sand) with sufficient available phosphorus, total nitrogen and exchangeable potassium and pH of 5.47 at Kiimbwanindi. The soil chemical properties were optimal hence the locations were suitable for the cassava production (Soil staff, 1993).

Table 2.1: Soil characteristics of the studied sites

Parameter	Method used	Ilonga		Kiimbwanindi		Range suitable for cassava production	Rated according to:
		0-20 cm	21-50 cm	0-20 cm	21-50 cm		
pH (in H ₂ O)	pH meter	5.88	5.61	5.47	5.24	4.5 - 7.0	CIAT (2011)
OC (%)	Walkley - Black	1.48	1.26	0.66	0.3	4.0 - 10.0	Landon (2014)
P (mgkg ⁻¹)	Bray 1	5.07	2.86	10.79	5.86	< 4.2	Howeler (2002)
N (%)	Kjeldahl	0.25	0.2	0.25	0.2	0.20 - 0.50	Landon (2014)
Ca (cmol _c kg ⁻¹)	Ammonium	10.8	10.82	2.21	0.93	1.0 - 5.0	CIAT (2011)
Mg (cmol _c kg ⁻¹)	Acetate	2.57	2.66	0.9	0.32	0.40 - 1.00	CIAT (2011)
K (cmol _c kg ⁻¹)	Extraction pH	0.67	0.38	0.23	0.17	0.15 - 0.25	CIAT (2011)
Na (cmol _c kg ⁻¹)	7.0	0.08	0.12	0.04	0.03	< 2	Howeler (2002)
Cu (mgkg ⁻¹)		2.04	2.24	0.6	0.83	0.3 - 0.8	Motsara and Roy (2008)
Zn (mgkg ⁻¹)	DTPA	0.59	0.39	2.07	1.18	1.0 - 3.0	Motsara and Roy (2008)
Mn (mgkg ⁻¹)	Extraction pH	21.5	21.31	26.61	26.92	1.2 - 3.5	Motsara and Roy (2008)
Fe (mgkg ⁻¹)	7.3	55.35	50.56	20	22.39	4.0 - 6.0	Motsara and Roy (2008)
Textural class	Hydrometer	SCL	SCL	LS	SL		

SCL = silty clay loam soil, LS = loamy sand soil and SL= sandy loam soil

2.4.2 Weed species, families and their lifecycle

The results of the occurred weeds in the survey fields are presented in Table 2.2. A total of 22 weed species belonging to 16 families were identified. The 16 weed families include Poaceae with five species, Asteraceae and Fabaceae with two species each and Agaricaceae, Apocynaceae, Boraginaceae, Commelinaceae, Convolvulaceae, Cyperaceae, Euphorbiaceae, Lamiaceae, Nyctaginaceae, Phyllanthaceae, Portulacaceae, Celastraceae, and Malvaceae had one species. Out of the identified weed species, 14 were broadleaf weeds, 6 grassy weeds, 1 mushroom and 1 sedge weed.

Table 2.2: Weed species, families and habit found in the selected cassava farms during the 2019/2020 season in both sites

Sn	Scientific name	Family	Life cycle	Type
1	<i>Agaricus</i> sp	Agaricaceae	Annual	Mushroom
2	<i>Asclepias syriaca</i>	Apocynaceae	Perennial	Broad leaves
3	<i>Bidens pilosa</i>	Asteraceae	Annual	Broad leaves
4	<i>Tridax procumbens</i>	Asteraceae	Perennial	Broad leaves
5	<i>Trichodesma zeylanicum</i>	Boraginaceae	Annual	Broad leaves
6	<i>Reissantia</i> sp	Celastraceae	Perennial	Broad leaves
7	<i>Commelina benghalensis</i>	Commelinaceae	Perennial	Grass
8	<i>Ipomoea</i> sp	Convolvulaceae	Perennial	Broad leaves
9	<i>Cyperus rotundus</i>	Cyperaceae	Perennial	Sedge
10	<i>Euphorbia hirta</i>	Euphorbiaceae	Annual	Broad leaves
11	<i>Mucuna pruriens</i>	Fabaceae	Annual	Broad leaves
12	<i>Tephrosia</i> sp	Fabaceae	Perennial	Broad leaves
13	<i>Ocimum gratissimum</i>	Lamiaceae	Perennial	Broad leaves
14	<i>Corchorus olitorius</i>	Malvaceae	Annual	Broad leaves
15	<i>Boerhavia erecta</i>	Nyctaginaceae	Annual/Perennial	Broad leaves
16	<i>Phyllanthus amarus</i>	Phyllanthaceae	Annual	Broad leaves
17	<i>Echinochloa colona</i>	Poaceae	Annual	Grass
18	<i>Cynodon nlemfuensis</i>	Poaceae	Perennial	Grass
19	<i>Cynodon plectostachyus</i>	Poaceae	Perennial	Grass
20	<i>Dactyloctenium aegyptium</i>	Poaceae	Annual	Grass
21	<i>Digitaria</i> sp	Poaceae	Annual	Grass
22	<i>Portulaca oleracea</i>	Portulacaceae	Annual	Broad leaves

2.4.3 Weed density, uniformity, frequency and relative abundance

Table 2.3 shows the result of density, uniformity, frequency and relative abundance of weeds found in the selected farm at Ilonga site. *Cyperus rotundus* occurred in highest mean field densities followed by *Echinochloa colona* while *Bidens pilosa*, *Portulaca oleracea* and *Agaricus sp* were least in density. *Cyperus rotundus*, *Echinochloa colona* and *Trichodesma zeylanicum* were the highest occurring with the highest relative abundance and the most disturbing weed species at the studied sites.

Table 2.3: Mean field density (MFD), relative mean density (RD), frequency (F), relative frequency (RF), uniformity (U), relative uniformity (RU) and relative abundance (RA) of weed species collected during the 2019/2020 season at Ilonga site.

S N	Weed species	MFD (plant/m ²)	RD (%)	F (%)	RF (%)	U (%)	RU (%)	RA (%)
1	<i>Cyperus rotundus</i>	258.25	71.27	100.0	5.88	100.0	22.64	99.80
2	<i>Echinochloa colona</i>	78.79	21.75	100.0	5.88	100.0	22.64	50.27
3	<i>Trichodesma zeylanicum</i>	18.58	5.13	100.0	5.88	87.50	19.81	30.82
4	<i>Cynodon plectostachyus</i>	1.92	0.53	100.0	5.88	25.00	5.66	12.07
5	<i>Commelina benghalensis</i>	1.21	0.33	100.0	5.88	25.00	5.66	11.88
6	<i>Corchorus olitorius</i>	0.29	0.08	100.0	5.88	16.67	3.77	9.74
7	<i>Veratrum sp</i>	1.00	0.28	100.0	5.88	12.50	2.83	8.99
8	<i>Boerhavia erecta</i>	0.63	0.17	100.0	5.88	12.50	2.83	8.89
9	<i>Asclepias syriaca</i>	0.54	0.15	100.0	5.88	12.50	2.83	8.86
10	<i>Phyllanthus amarus</i>	0.17	0.05	100.0	5.88	12.50	2.83	8.76
11	<i>Tridax procumbens</i>	0.17	0.05	100.0	5.88	8.33	1.89	7.82
12	<i>Euphorbia hirta</i>	0.13	0.03	100.0	5.88	8.33	1.89	7.80
13	<i>Cynodon nlemfuensis</i>	0.46	0.13	100.0	5.88	4.17	0.94	6.95
14	<i>Dactyloctenium aegyptium</i>	0.08	0.02	100.0	5.88	4.17	0.94	6.85
15	<i>Bidens pilosa</i>	0.04	0.01	100.0	5.88	4.17	0.94	6.84
16	<i>Portulaca oleracea</i>	0.04	0.01	100.0	5.88	4.17	0.94	6.84
17	<i>Agaricus sp</i>	0.04	0.01	100.0	5.88	4.17	0.94	6.84

Table 2.4 shows the result of density, uniformity, frequency and relative abundance of weeds found in the selected farm at Kiimbwanindi site. *Reissantia sp* occurred in highest mean field densities followed by *Mucuna pruriens* while other weed species found to be very minimal. *Reissantia sp*, *Mucuna pruriens*, *Cyperus rotundus* and *Commelina benghalensis* were the highest occurred and the most disturbing weed species at this site.

Table 2.4: Mean field density (MFD), relative mean density (RD), frequency (F), relative frequency (RF), uniformity (U), relative uniformity (RU) and relative abundance (RA) of weed species collected during the 2019/2020 season at Kiimbwanindi site.

S N	Weed species	MFD (plant/m ²)	RD (%)	F (%)	RF (%)	U (%)	RU (%)	RA (%)	
1	<i>Reissantia</i> sp	6.17	37.95	100.0	0	12.50	7	33.33	83.78
2	<i>Mucuna pruriens</i>	5.00	30.77	100.0	0	12.50	7	28.79	72.06
3	<i>Cyperus rotundus</i>	1.75	10.77	100.0	0	12.50	3	12.12	35.39
4	<i>Commelina benghalensis</i>	2.46	15.13	100.0	0	12.50	3	7.58	35.20
5	<i>Digitaria</i> sp	0.42	2.56	100.0	0	12.50	0	9.09	24.16
6	<i>Tephrosia</i> sp	0.17	1.03	100.0	0	12.50	8.33	3.03	16.56
7	<i>Cynodon plectostachyus</i>	0.17	1.03	100.0	0	12.50	8.33	3.03	16.56
8	<i>Ipomoea</i> sp	0.13	0.77	100.0	0	12.50	8.33	3.03	16.30

Table 2.5 shows the combined result of density, uniformity, frequency and relative abundance of weeds found in the studied areas. *Cyperus rotundus* occurred in high mean field densities of 130 plants m⁻² followed by *Echinochloa colona* which occurred in 39.4 plants m⁻² while *Euphorbia hirta*, *Ipomoea* sp, *Dactyloctenium aegyptium*, *Bidens pilosa*, *Portulaca oleracea* and *Agaricus* sp were least in density in descending order ranging from 0.06 to 0.02 plants m⁻² mean field densities. The most widespread weed species in terms of frequency was *Cyperus rotundus*, *Cynodon plectostachyus* and *Commelina benghalensis*.

Cyperus rotundus with 87.59% relative abundance, *Echinochloa colona* with 41.19% relative abundance, *Trichodesma zeylanicum* with 23.24% relative abundance and

Reissantia sp with 20.65% relative abundance were the highest occurred and the most disturbing weed species in the studied sites.

Table 2.5: Frequency (F), relative frequency (RF), uniformity (U), relative uniformity (RU), mean field density (MFD), relative mean density (RD), and relative abundance (RA) of the 22 weed species collected during the 2019/2020 season in selected cassava fields in Eastern zone, Tanzania.

Sn	Weed	F (%)	RF (%)	MFD (plant/m ²)	RD (%)	U (%)	RU (%)	RA (%)
1	<i>Cyperus rotundus</i>	100	8.00	130	68.67	66.67	10.92	87.59
2	<i>Echinochloa colona</i>	50	4.00	39.40	20.81	100.00	16.38	41.19
3	<i>Trichodesma zeylanicum</i>	50	4.00	9.29	4.91	87.50	14.33	23.24
4	<i>Reissantia</i> sp	50	4.00	3.08	1.63	91.67	15.02	20.65
5	<i>Mucuna pruriens</i>	50	4.00	2.50	1.32	79.17	12.97	18.29
6	<i>Commelina benghalensis</i>	100	8.00	1.83	0.97	22.92	3.75	12.72
7	<i>Cynodon plectostachyus</i>	100	8.00	1.04	0.55	16.67	2.73	11.28
8	<i>Digitaria</i> sp	50	4.00	0.21	0.11	25.00	4.10	8.21
9	<i>Corchorus olitorius</i>	50	4.00	0.15	0.08	16.67	2.73	6.81
1								
0	<i>Ocimum gratissimum</i>	50	4.00	0.50	0.26	12.50	2.05	6.31
1								
1	<i>Boerhavia erecta</i>	50	4.00	0.31	0.17	12.50	2.05	6.21
1								
2	<i>Asclepias syriaca</i>	50	4.00	0.27	0.14	12.50	2.05	6.19
1								
3	<i>Phyllanthus amarus</i>	50	4.00	0.08	0.04	12.50	2.05	6.09
1								
4	<i>Tridax procumbens</i>	50	4.00	0.08	0.04	8.33	1.37	5.41
1								
5	<i>Tephrosia</i> sp	50	4.00	0.08	0.04	8.33	1.37	5.41
1								
6	<i>Euphorbia hirta</i>	50	4.00	0.06	0.03	8.33	1.37	5.40
1								
7	<i>Ipomoea</i> sp	50	4.00	0.06	0.03	8.33	1.37	5.40
1								
8	<i>Cynodon nlemfuensis</i>	50	4.00	0.23	0.12	4.17	0.68	4.80
1	<i>Dactyloctenium</i>							
9	<i>aegyptium</i>	50	4.00	0.04	0.02	4.17	0.68	4.70
2								
0	<i>Bidens pilosa</i>	50	4.00	0.02	0.01	4.17	0.68	4.69
2								
1	<i>Portulaca oleracea</i>	50	4.00	0.02	0.01	4.17	0.68	4.69
2								
2	<i>Agaricus</i> sp	50	4.00	0.02	0.01	4.17	0.68	4.69

2.4.4 A weed compendium

All weeds found in the selected farms in both sites were recorded. These weeds were then identified to species level, their habit and morphological characteristics. A total of 57

weeds belonging to 28 families were identified within and out of the random placed quadrats Appendix 1. Sample of weed pictures presented (Figure 1) below:



Ageratum conyzoides



Commelina benghalensis

Figure 2.1: Weeds found in the selected farms

2.5 Discussion

Weed density, uniformity, frequency and relative abundance from the studied sites

In the studied areas where cassava was grown, perennial weeds such as *Cyperus rotundus* tend to dominate with high density (130 plantsm⁻²) as compared to annual weeds. This might be attributed to the reproductive ability of these perennial species, their ability to make use of the available resources in the soil and history of previous cropping systems

and weed management practices. Similar results were reported by Olorunmaiye *et al.* (2013) who reported the high presence of perennial weeds in cassava fields.

Frequency describes the percentage of the fields that are infested with weeds, so as having high frequency is the indication of the availability of the mentioned weed in that cassava fields. In the studied sites, perennial weeds *Commelina benghalensis*, *Cynodon* species and *Cyperus rotundus* had highest frequency which shows these weeds were highly adapted to the environment as compared to other weeds. Similar results to this were reported by Ekeleme *et al.* (2019), who stated that, environments where cassava is growing tend to be dominated by perennial weed species such as *Imperata cylindrica*, *Panicum maximum*, *Cyperus rotundus*, and *Mimosa invisa*.

Weed uniformity indicates how even the weeds are, across the fields. Weeds like *Cynodon nlemfuensis*, *Dactyloctenium aegyptium*, *Bidens pilosa*, *Portulaca oleracea* and *Agaricus sp* had the lowest uniformity which indicate they were only found in patches while, weeds such as *Echinochloa colona*, *Reissantia sp*, *Trichodesma zeylanicum*, *Mucuna pruriens* and *Cyperus rotundus* showed the highest uniformity than others

In this study, *Commelina benghalensis*, *Cynodon spp* and *Cyperus rotundus* were found at all selected fields but they varied in their relative abundance. *Cyperus rotundus* was highly abundant weed (87.59%) followed by *Echinochloa colona* (41.19%) and *Trichodesma zeylanicum* (23.24%). This highly abundance of these weeds is the due to their high density and frequency which reflect their dominance to the fields. *Cyperus rotundus* was abundant possibly due to its ability to grow in almost every soil type and over a wide range of soil moisture, pH and elevation as it grows best in moist fertile soils, it has effective penetration and dispersion structure (nuts) and also frequent cultivation

has been suggested to promote/favor its growth. Similar results were reported by Olorunmaiye *et al.* (2013) that *Cyperus rotundus* can grow over a high range of soil types. *Reissantia sp*, *Mucuna pruriens* and *Commelina benghalensis* having 20.65%, 18.29% and 12.72%, respectively, were also highly abundant weed species, that might be due to their ability to reproduce both sexually and asexually and highly adapted to the areas with temperature ranging from 30° C to 35° C (Webster *et al.*, 2005) similar to that of studied sites.

2.6 Conclusion and Recommendations

2.6.1 Conclusion

The study identified common weed species that are mostly found in cassava fields in Eastern zone Tanzania, and indicated that, perennial weeds *Cyperus rotundus*, *Echinochloa colona*, *Trichodesma zeylanicum*, *Reissantia sp*, *Mucuna pruriens* and *Commelina benghalensis* are the most and abundant occurring weed species with intrinsic adaptive characteristics compared to other species. The study document probably the first-time common weeds and their behavior as influenced by density, uniformity, frequency and relative abundance as they are associated with cassava production systems in Eastern zone Tanzania.

2.6.2 Recommendations

Following the results of this research work, the following are recommended

- i. More research works are needed on regular basis to identify possible weeds population shifts.
- ii. More researches toward new or improved weed control measures are needed.
- iii. Farmers should be sensitized and trained on weed management practices for increased cassava yield to optimum level.

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CHAPTER THREE

3.0 EFFECT OF TILLAGE, PRE-EMERGENCE AND POST-EMERGENCE WEED CONTROL OPTIONS ON WEED GROWTH, CASSAVA YIELD AND SOIL QUALITY

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3.1 Abstract

Weeds are among the major pest that hinders cassava production. Poor and improper weeding has been reported to cause cassava root yield losses ranging from 40% to 90%. The effect of different weed control treatment combinations was conducted in Ilonga village, Kilosa district and Kiimbwanindi village, Mkuranga district during 2019/2020 planting season. Till only and till + Ridge, pre-emergence herbicides (Primagram Gold a.i 290 g/L S-metolachlor + 370 g/L atrazine and Oxfen a.i Oxyfluorfen 24% EC), post emergence herbicides (Force up a.i 480 g/L of Glyphosate-Isopropylamine salt and back pack weeder with modified tines were tested on Cassava variety Kiroba in a factorial experiment arranged in a randomized complete block design (RCBD) replicated three times.

Combination of tillage practices and pre-emergence herbicides application increased number of days weeds took to emerge in both sites. The correlation analysis showed a non-significant positive relationship, $r = 0.389$, $p > 0.05$ and $r = 0.055$, $p > 0.05$ between cassava stem height and cassava fresh root weight, and cassava stem girth and cassava

fresh root weight, respectively at Kiimbwanindi site and highly significant strong positive relationship, $r = 0.925$, $p < 0.001$ and $r = 0.781$, $p < 0.05$ between cassava stem height and cassava fresh root weight, and cassava stem girth and cassava fresh root weight, respectively at Ilonga site. Weed control combinations significantly affected cassava fresh root weight and biomass, $p = 0.019$ and $p = 0.026$, respectively at Kiimbwanindi. At Ilonga, they did not significantly affect the cassava fresh root weight, $p = 0.514$ and cassava biomass $p = 0.732$. Also weed control combinations did not significantly affect soil quality.

The combination of till + ridges, application of pre-emergence herbicide (S-metolachlor + atrazine) and post emergence herbicides (glyphosate) provided favorable environment for cassava growth and root formation as compared to other treatment combinations. Therefore, it is recommended as a best option for controlling weeds in cassava production system.

Keywords: *Weed control combinations, Days after planting, Fresh root weight, Biomass*

3.2 Introduction

Weeds are the major pests that hinder cassava production as they cause competition for light, water and plant nutrient. Also, weeds could be a host for insects and disease pathogens for cassava (Islami *et al.*, 2017). In cassava production, weed control within the first several weeks after planting is critical in order to avoid yield loss. Poor and improper weeding has been reported to cause cassava root yield losses ranging from 40% to 90% (Chikoye *et al.*, 2001; Islami *et al.*, 2017; Ekeleme *et al.*, 2019). Due to that, various weed control options have been used in cassava production, those control methods are preventative, cultural, mechanical and chemical by which are most effective if applied at the proper time (Islami *et al.*, 2017; Sims *et al.*, 2018).

Soil tillage on weeding is the one of the weed control techniques which alters the soil physical properties, thus exposing weed seeds to conditions unfavorable for germinations that result in reducing weed germination ability and therefore, seedbank reduction. Schwartz-Lazaro and Copes (2019), indicated that tillage system and type of tillage to have influence on specific composition and density of the weed seedbank in the soil, and that intense tillage highly reduces weed seedbank and weed population. However, excessive tillage makes the soil prone to erosion and nutrients leaching (Ferrerias *et al.*, 2000; Jongruaysup *et al.*, 2007; Figueiredo *et al.*, 2017), resulting to soil fertility decline which is less productive to cassava and other crops.

Herbicides are effective in controlling weeds if applied at appropriate rate and time specifically for weed and crop growth stages and for a specific weed type and crop (Schwartz-Lazaro and Copes, 2019). Some herbicides are soil applied (pre-emergence herbicides) which control weeds as seeds germinate, and reduce early-season weed competition. The important factors to consider during application of herbicides include

soil type, environmental impacts such as leaching or runoff potential, target weeds and objectives of the application (Kraehmer *et al.*, 2014; Ekeleme *et al.*, 2016). Other herbicides are post-emergence whose applications target weed species not controlled by soil applications. These herbicides can either control weeds emerged at the time of application or already emerged weeds and provide residual activity against late emerging weeds (Kraehmer *et al.*, 2014). Weed control using herbicides in cassava cultivation has been reported by Gianessi and Williams (2016) and Islami *et al.* (2017) to be beneficial to both soil and the crop as it can improve soil quality and reduces soil erosion. Furtherer, other studies revealed that excessive and/or improper use of herbicide can also cause detrimental effects such as environmental pollution, affect human health and evolution of resistant weeds (Islami *et al.*, 2017; Westwood *et al.*, 2018).

However, some of these methods require huge labor force and a lot of time. For instance, hand hoe weeding requires 50 to 80% of the total labor budget in production and as many as 200 to 500 hours of labor per hectare resulting in delaying in weeding activity thus reduction in cassava root yield to about 20 to 50% (Reshma *et al.*, 2016; Sims *et al.*, 2018; Ekeleme *et al.*, 2019). Reshma *et al.* (2016) reported that cassava requires good weed management during the first three to four months after planting, as it has a tendency of exhibiting slow initial growth and incomplete canopy cover, thus the effectiveness of any weed control measures depends largely on timeliness of application. When the fields are kept free from weeds for the first several weeks after planting, it gives the cassava a competitive edge that allows it to shade out and out compete weeds that would emerge late in the season. Therefore, this study was conducted to determine the best package from different integrated weed control techniques which will keep cassava farm free from weeds for a longer period of time and resulting to optimum cassava root yield production.

3.3 Materials and Methods

3.3.1 Description of the study sites

The study was conducted in Ilonga village, Kilosa district, Morogoro region at a geographical location of latitude 6°46' 27" S and longitude 37°2'14" E, and elevation of 479.95 masl and Kiimbwanindi village, Mkuranga district, Coastal region at latitude 7°12'19" S, longitude 39°20'38" E and elevation of 93.87 masl. At Kiimbwanindi, the average monthly temperature ranges from a low of around 18.8 °C during the coolest months of July and August to the highest monthly means of 31.9 °C to 32.6 °C during the hot season from December to March. Relative humidity ranges from 67-70 % from August to October, increasing to 82 % during the wettest months of April. The average annual rainfall is 1,073 mm (ranging from 585 mm to 1,536 mm). Mkuranga district experiences bi-modal rainfall pattern; March to May (main wet season) with about 550 mm of rain and November to December (short rains) with 235 mm of rain (Mkuranga, 2009; RCO, 2011). At Kilosa, the district experiences an average of eight months of rainfall (October to May), with the highest levels between February and March. The rainfall distribution is weakly bimodal in good years, with short rains (October to January), followed by long rains (mid-February to May). Mean annual rainfall ranges between 1 000 and 1 400 mm in the southern flood plain, while further north (Gairo Division) the annual rainfall ranges from 800 to 1,100 mm. The mean annual temperature in Kilosa district is about 25°C (Kajembe *et al.*, 2013; Zakayo, 2015).

3.3.2 Treatments and experimental design

Experimental design used was factorial experiment ($2 \times 2 \times 2$) arranged in randomized complete block design, whereby eight plots were established to make one replication. Plot size was 20 m² (4 m × 5 m) and plots were separated by 1 m and replication was separated by 2 m. Treatments were replicated three times in each site.

Treatments were two tillage practices (Till only and till + Ridge), two pre-emergence weed control options (herbicide) (Primagram Gold a.i 290 g/L S-metolachlor and 370 g/L atrazine and Oxfen a.i Oxyfluorfen 24% EC) and two post emergence weed control options (herbicide; Force up a.i 480 g/L of Glyphosate-Isopropylamine salt and mechanized weeder tool; back pack weeder with modified tines). Pre emergence weed control treatment was applied at planting. Post emergence weed control treatments were applied when weed population reached 30% (three to four leaves stage) within a plot as per IITA (ACAI project) protocol (Kodjovi *et al.*, 2018). Cassava (Kiroba variety) planted at a population of 10 000 plants/ha was used. Fertilizer was applied as recommended by Akilimo application.

3.3.3 Data collection

3.3.3.1 Crop data collected:

Sprout count: Number of cassava stalks that emerged 4 weeks after planting (WAP) were recorded.

Growth characteristics: After treatments application five months after planting (5 MAP), data on cassava stem height and girth were collected.

Harvest data: On the 10th MAP, the above ground plant parts (leaves with petioles, stem and planting stalk) and roots were weighed to determine harvest index (plant biomass).

For the roots; data on number of marketable/storage cassava roots, cassava root yield (fresh root weight per plant, fresh root weight per Ha, dry storage root weight per 500 g sample of cassava root according to Edet *et al.*, (2015) were recorded. Dry matter content was estimated after oven dry at 105°C for 24 hours according to Ntawuruhunga and Dixon, (2010). These data were collected from two middle rows in the plot leaving two lines on each side of the plot as borders.

3.3.3.2 Weed data collected: Weed density, weed species and time at which weed population reaches 30% (three to four leaves stage) were recorded in order to determine the duration at which pre-emergence and post emergence weed control treatments suppressed weed growth as per Moeini *et al.* (2008) procedure.

3.3.3.3 Soil data collected: Soil samples were collected using an auger in each field at the depth of 0 – 20 cm and 21 – 50 cm before land preparation for assessment of the initial soil fertility status. A total of five samples were collected following a zigzag pattern at each depth to make a compost sample and then this sample was used to make a single sample (Jones, 2012).

3.3.4 Data analysis

The data collected were subjected to analysis of variance (ANOVA) at ($P \leq 0.05$) using R statistical package version 3.5.2. The treatment means were compared using Tukey's honestly significance test at alpha 5%. Correlation analysis (Pearson's correlation coefficients) was performed among variables. The data from each site were analyzed separately and then sites were compared using a paired-samples t-test.

Also, both physical and chemical characteristics of the soil sample collected were determined by its respective method as mentioned in table 3.1. All analyses were done following the procedures by Jones (2012).

3.4 Results

3.4.1 Physical and chemical characteristics of the soils at the studied sites

Soil chemical characteristics and particle size class of the surface and subsurface soils (0 to 20 cm and 21 to 50 cm deep) at both experimental sites in 2019/2020 planting season are shown in Table 3.1. The soil of Ilonga site found to be silty clay loam (24% clay, 15% silt and 61% sand) with sufficient available phosphorus, total nitrogen and exchangeable

potassium and pH of 5.88. At Kiimbwanindi, the soil was loamy sand (12% clay, 3% silt and 85% sand) with sufficient available phosphorus, total nitrogen and exchangeable potassium and pH of 5.47. The soil conditions of the sites were optimal hence the locations support the cassava production (Soil staff, 1993).

Table 3.1: Soil characteristics of the studied areas

Parameter	Method used	Ilonga		Kiimbwanindi		Range suitable for cassava production	Rated according to:
		0-20 cm	21-50 cm	0-20 cm	21-50 cm		
pH (in H ₂ O)	pH meter	5.88	5.61	5.47	5.24	4.5 - 7.0	CIAT (2011)
OC (%)	Walkley - Black	1.48	1.26	0.66	0.3	4.0 - 10.0	Landon (2014)
P (mgkg ⁻¹)	Bray 1	5.07	2.86	10.79	5.86	< 4.2	Howeler (2002)
N (%)	Kjeldahl	0.25	0.2	0.25	0.2	0.20 - 0.50	Landon (2014)
Ca (cmol _c kg ⁻¹)	Ammonium	10.8	10.82	2.21	0.93	1.0 - 5.0	CIAT (2011)
Mg (cmol _c kg ⁻¹)	Acetate	2.57	2.66	0.9	0.32	0.40 - 1.00	CIAT (2011)
K (cmol _c kg ⁻¹)	Extraction pH	0.67	0.38	0.23	0.17	0.15 - 0.25	CIAT (2011)
Na (cmol _c kg ⁻¹)	7.0	0.08	0.12	0.04	0.03	< 2	Howeler (2002)
Cu (mgkg ⁻¹)		2.04	2.24	0.6	0.83	0.3 - 0.8	Motsara and Roy (2008)
Zn (mgkg ⁻¹)	DTPA	0.59	0.39	2.07	1.18	1.0 - 3.0	Motsara and Roy (2008)
Mn (mgkg ⁻¹)	Extraction pH	21.5	21.31	26.61	26.92	1.2 - 3.5	Motsara and Roy (2008)
Fe (mgkg ⁻¹)	7.3	55.35	50.56	20	22.39	4.0 - 6.0	Motsara and Roy (2008)
Textural class	Hydrometer	SCL	SCL	LS	SL		

SCL = silty clay loam soil, LS = loamy sand soil and SL = is sandy loam soil

3.4.2 Influence of tillage practice, pre-emergence weed control and post emergence weed control treatments on weed growth

a) Days to first post emergence weed control

The results on effect of tillage practice, pre-emergence weed control treatments and post emergence weed control treatments on days to first post emergence weed control treatment application for both Kiimbwanindi and Ilonga sites are shown in Table 3.2. There was a highly significant ($p < 0.001$) effect of tillage practice on a number of days to the first post emergence weed control treatments application for both sites. At both sites,

the application of tillage and ridging resulted into the highest number of days to first post emergence weed control treatments application.

Additionally, there was a highly significant ($p < 0.001$) effect of pre-emergence weed control treatments on a number of days to weeds emergence for both sites. The application of Primagram gold as pre-emergence herbicide showed the highest number of days to weed emergence at both sites.

There was a significant ($p < 0.05$) effect of post emergence treatment application on the days to weeds reemergence at Kiimbwanindi site while there was no significance ($p > 0.05$) at Ilonga site. The application of Force up herbicide as a post-emergence treatment led into the highest number of days for both site that weeds took to reach three leaves stage.

b) Days to second post emergence weed control

Table 3.2 show the results on effect of tillage practice, pre-emergence weed control and post emergence weed control treatments on weed growth after the first post emergence weed control treatment application for both Kiimbwanindi and Ilonga sites. The results showed that, there was a highly significant ($p < 0.001$) effect of tillage practice on days to second post emergence weed control treatments application whereby till and ridge showed highest number of days to second post emergence weed control treatments application at both sites.

There was a highly significant ($p < 0.001$) effect of pre-emergence weed control treatments on days to second post emergence weed control treatments application at Kiimbwanindi site while there was no significant ($p > 0.05$) effect of pre-emergence weed control treatments on days to second post emergence weed control treatment application at Ilonga

site. The application of Primagram gold as pre-emergence herbicide showed the highest number of days to second post emergence weed control treatment application at both sites.

Furthermore, there was a highly significant ($p < 0.001$) effect of post emergence treatment application on days to second post emergence weed control treatment application in both sites. The application of Force up herbicide significantly increased the number of days to the second post emergence weed control treatments application at both sites.

Table 3.2: Influence of Tillage practice, Pre emergence and Post emergence weed control treatments on weed growth

Treatment factors		Days to 1 st PEWC	Days to 2 nd PEWC
Kiimbwanindi village			
Factor A (Tillage practice)	Till	30.17b	55.50b
	Till and Ridge	45.33a	70.00a
	<i>Mean</i>	37.75	62.75
	<i>p value</i>	<.0001	<.0001
Factor B (Pre emergence treatment)	Oxfen	33.37b	60.92b
	Primagram	41.83a	64.58a
	<i>Mean</i>	37.6	62.75
	<i>p value</i>	<.0001	0.0009
Factor C (Post emergence treatment)	Force up	38.67a	69.25a
	Mechanical weeding	36.83b	56.25b
	<i>Mean</i>	37.75	62.75
	<i>p value</i>	0.0322	<.0001
Ilonga village			
Factor A (Tillage practice)	Till	32.17b	70b
	Till and Ridge	44.08a	78.58a
	<i>Mean</i>	38.13	74.29
	<i>p value</i>	<.0001	<.0001
Factor B (Pre emergence treatment)	Oxfen	35.58b	74.08a
	Primagram	40.67a	74.5a
	<i>Mean</i>	38.13	74.29
	<i>p value</i>	<.0001	0.6186
Factor C (Post emergence treatment)	Force up	38.08a	77.08a
	Mechanical weeding	38.17a	71.5b
	<i>Mean</i>	38.1	74.29
	<i>p value</i>	0.8619	<.0001

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test, PEWC = post emergence weed control.

3.4.3 Interaction's effect of weed control treatments on weeds growth

a) Days to first post emergence weed control

The results on the weed control treatment interaction on a number of days to the first post emergence weed control treatment application are shown in Table 3.3 and Table 3.4. At both sites, the combinations of tillage practices and pre-emergence weed control significantly ($p < 0.05$) increased the number of days to weed reemergence. Till and ridge \times Primagram herbicide treatment combinations, controlled weeds for more days, while on plots where till \times Oxfen treatment combination were applied showed the lowest number at both sites.

The combination of tillage practices and post emergence weed control showed no significant ($p > 0.05$) increase on the number of days to weed emergence at Kiimbwanindi site while significantly ($p < 0.05$) increased the number of days at Ilonga site. Till and ridge \times Force up herbicide treatment combinations, controlled weeds for more days, while on plots where till \times Force up herbicide treatment combinations were applied had the lowest number of days at both sites.

The combination of pre-emergence weed control and post emergence weed control treatments did not significantly ($p > 0.05$) increase the number of days to weed emergence at both sites. Primagram herbicide \times Force up herbicide treatment combinations, controlled weeds for more days, while on plots where Oxfen \times mechanical weeding treatment combinations were applied had the lowest number of days at both sites.

The application of tillage practice, pre-emergence herbicides and post emergence weed control treatment combinations did not significantly ($p > 0.05$) increase the number of days to weed emergence at both sites. Till and ridge \times Primagram \times Force up treatment

combinations showed the highest number of days while till × Oxfen × Force up showed the lowest number of days at both sites.

b) Days to second post emergence weed control

The results on effect of tillage practice, pre-emergence and post emergence weed control treatment interactions on days to second post emergence weed control treatment application are shown in Table 3.3 and Table 3.4 for Kiimbwanindi and Ilonga sites, respectively. The combinations of tillage practices and pre-emergence weed control significantly ($p < 0.05$) increased the number of days to second post emergence weed control treatment application. At both sites, till and ridge × Primagram herbicide treatment combinations-controlled weeds for more days. The plots where till × Oxfen treatment combinations were applied showed the lowest number of days at Kiimbwanindi, while till × Primagram treatment combinations showed the lowest number of days at Ilonga site.

The combinations of tillage practices and post emergence weed control treatments significantly ($p < 0.05$) increased the number of days to second post emergence weed control treatment application at both sites. At both sites, till and ridge × Force up herbicide treatment combinations-controlled weeds for more days. The plots where till × mechanical weeding treatment combinations were applied had the lowest number of days at Kiimbwanindi while plots where till × Force up herbicide treatment combinations were applied had the lowest number of days at Ilonga.

The combinations of pre-emergence weed control and post emergence weed control treatments did not significantly ($p > 0.05$) increase the number of days to second post emergence weed control treatment application at both sites. Primagram herbicide × Force up herbicide treatment combination-controlled weeds for more days at both sites. The

plots where Oxfen × mechanical weeding treatment combinations were applied had the lowest number of days at Kiimbwanindi while plots where Primagram × mechanical weeding treatment combinations were applied had the lowest number of days at Ilonga site.

The application of tillage practice, pre-emergence herbicides and post emergence weed control treatment combinations did not significantly ($p > 0.05$) increase the average number of days to the second post emergence weed control treatment application at Kiimbwanindi site. Till and ridge × Primagram × Force up treatment combinations showed the highest number of days followed by Till and ridge × Oxfen × Force up treatment combinations and till × Primagram × mechanical weeding and till × Oxfen × mechanical weeding had the lowest number of days.

The application of tillage practice, pre-emergence herbicides and post emergence weed control treatment combinations significantly ($p \leq 0.05$) increased the number of days to the second post emergence weed control treatment application at Ilonga. Till and ridge × Primagram × Force up treatment combinations showed the highest number of days and till × Primagram × Force up showed the lowest number of days. During this stage of post emergence treatment application, perennial weeds; *Cyperus rotundus*, *Cynodon species* and *Reissantia sp* were predominant at both sites.

**Table 3.3: Interaction effect of weed control treatments on weed growth at
Kiimbwanindi site**

Treatment factors		Days to 1 st PEWC	Days to 2 nd PEWC
A × B	Till × Oxfen	28.00d	55.17c
	Till × Primagram	32.33c	55.83c
	Till and Ridge × Oxfen	39.33b	66.67b
	Till and Ridge × Primagram	51.33a	73.33a
	<i>p value</i>	0.0002	0.0044
A × C	Till × Force up	30.33c	59.67b
	Till × Mechanical weeding	30.00c	51.33c
	Till and Ridge × Force up	47.00a	78.83a
	Till and Ridge × Mechanical weeding	43.67b	61.17b
	<i>p value</i>	0.073	<.0001
B × C	Oxfen × Force up	34.33b	67.17b
	Oxfen × Mechanical weeding	33.00b	54.67c
	Primagram × Force up	43.00a	71.33a
	Primagram × Mechanical weeding	40.67a	57.67c
	<i>p value</i>	0.5315	0.5883
A × B × C	Till × Oxfen × Force up	28.00d	59.33c
	Till × Oxfen × Mechanical weeding	28.00d	51.00d
	Till × Primagram × Force up	32.67cd	60.00c
	Till × Primagram × Mechanical weeding	32.00d	51.67d
	Till and Ridge × Oxfen × Force up	40.67b	75.00b
	Till and Ridge × Oxfen × Mechanical weeding	38.00bc	58.33c
	Till and Ridge × Primagram × Force up	53.33a	82.67a
	Till and Ridge × Primagram × Mechanical weeding	49.33a	64.00c
Mean	37.75	62.75	
CV%	5.4	3.5	
<i>p value</i>	0.8339	0.5883	

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test, CV = coefficient of variation,

PEWC = post emergence weed control, A = Tillage practice, B = Pre emergence weed control treatment, C = Post emergence weed control treatment.

Table 3.4: Interaction effect of weed control treatments on weed growth at Ilonga site

Treatments factors		Days to 1 st PEWC	Days to 2 nd PEWC
A × B	Till × Oxfen	29d	71b
	Till × Primagram	35.33c	69b
	Till and Ridge × Oxfen	42.17b	77.17a
	Till and Ridge × Primagram	46a	80a
	<i>p value</i>	0.0174	0.0095
A × C	Till × Force up	31.5b	69b
	Till × Mechanical weeding	32.83b	71b
	Till and Ridge × Force up	44.67a	85.17a
	Till and Ridge × Mechanical weeding	43.5a	72b
	<i>p value</i>	0.0174	<.0001
B × C	Oxfen × Force up	36.17b	76.17a
	Oxfen × Mechanical weeding	36b	72b
	Primagram × Force up	41a	78a
	Primagram × Mechanical weeding	40.33a	71b
	<i>p value</i>	0.1312	0.1036
A × B × C	Till × Oxfen × Force up	28d	71cd
	Till × Oxfen × Mechanical weeding	30d	71cd
	Till × Primagram × Force up	35c	67d
	Till × Primagram × Mechanical weeding	35.67c	71cd
	Till and Ridge × Oxfen × Force up	42.33b	81.33b
	Till and Ridge × Oxfen × Mechanical weeding	42b	73c
	Till and Ridge × Primagram × Force up	47a	89a
	Till and Ridge × Primagram × Mechanical weeding	45ab	71cd
<i>Mean</i>	38.12	74.29	
<i>CV%</i>	3.2	2.7	
<i>p value</i>	0.8619	0.0007	

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test, CV = coefficient of variation, PEWC = post emergence weed control, A = Tillage practice, B = Pre emergence weed control treatment, C = Post emergence weed control treatment.

3.4.4 Influence of tillage practice, pre-emergence and post emergence weed control treatments on cassava plant height and stem girth at 5 months after planting

The results in Table 3.5 shows that there was no significant ($p>0.005$) influence of tillage practices on cassava plant height and stem girth at five months after planting between treatments at Kiimbwanindi site. The highest plant height and stem girth was on the till and ridge treatment. While at Ilonga site, tillage practices significantly ($p<0.05$) affected the cassava plant height and stem girth. Till and ridge treatment led to the highest stem height and stem girth.

There was no significant ($p>0.05$) effect of pre-emergence weed control treatments on cassava plant height and stem girth at 5 months after planting for both sites. At Kiimbwanindi site, Oxfen herbicide treatment applied as pre-emergence weed control showed the highest stem height and stem girth while at Ilonga site, Oxfen treatment applied as pre-emergence weed control showed the highest stem height and stem girth.

There was no significant ($p>0.05$) effect of post emergence weed control treatments on cassava plant height and stem girth at 5 months after planting for both sites. At Kiimbwanindi site, mechanical weeding treatment applied as post emergence weed control showed the highest stem height and stem girth while, at Ilonga site, force up herbicide applied as post emergence weed control recorded the highest stem height and stem girth.

Table 3.5: Influence of Tillage practice, Pre emergence and Post emergence weed control treatments on cassava plant height and stem girth at 5 months after planting

Treatment factors		Stem Height (cm)	Stem Girth (cm)
Kiimbwanindi village			
Factor A (Tillage practice)	Till	191.13a	10.04a
	Till and Ridge	194.42a	10.18a
	<i>Mean</i>	<i>192.78</i>	<i>10.11</i>
	<i>p value</i>	<i>0.7063</i>	<i>0.7445</i>
Factor B (Pre emergence treatment)	Oxfen	199.17a	10.3a
	Primagram	186.38a	9.93a
	<i>Mean</i>	<i>192.78</i>	<i>10.12</i>
	<i>p value</i>	<i>0.1554</i>	<i>0.393</i>
Factor C (Post emergence treatment)	Force up	189.25a	10.06a
	Mechanical weeding	196.29a	10.17a
	<i>Mean</i>	<i>192.77</i>	<i>10.12</i>
	<i>p value</i>	<i>0.4239</i>	<i>0.803</i>
Ilonga village			
Factor A (Tillage practice)	Till	62.0667b	6.56b
	Till and Ridge	81.6833a	7.53a
	<i>Mean</i>	<i>71.88</i>	<i>7.05</i>
	<i>p value</i>	<i>0.0119</i>	<i>0.0184</i>
Factor B (Pre emergence treatment)	Oxfen	72.25a	7.13a
	Primagram	71.5a	6.96a
	<i>Mean</i>	<i>71.88</i>	<i>7.05</i>
	<i>p value</i>	<i>0.915</i>	<i>0.6569</i>
Factor C (Post emergence treatment)	Force up	74.15a	7.26a
	Mechanical weeding	69.6a	6.83a
	<i>Mean</i>	<i>71.88</i>	<i>7.05</i>
	<i>p value</i>	<i>0.5201</i>	<i>0.2565</i>

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test

3.4.5 The influence of weed control treatment interactions on cassava plant height and stem girth at 5 months after planting

3.4.5.1 The influence of weed control treatment interactions on cassava plant height at 5 months after planting

Table 3.6 shows the influence of weed control treatment interactions on cassava plant height. At both sites the combinations of tillage practices and pre-emergence weed control treatments did not significantly ($p > 0.05$) affect the stem height. Till \times Oxfen treatment

combinations led to the highest stem height at Kiimbwanindi while Till and ridge × Oxfen treatment combinations, had the highest stem height at Ilonga site. Plots where till × Primagram herbicide treatment combinations were applied had the lowest stem height for both sites.

The combinations of tillage practices and post emergence weed control treatments did not significantly ($p>0.05$) affect the stem height at both sites. Till and ridge × Mechanical weeding treatment combinations showed the highest stem height at Kiimbwanindi while Till and ridge × Force up herbicide treatment combinations showed the highest stem height at Ilonga site. The plots where Till and ridge × Force up herbicide treatment combinations were applied showed the lowest stem height at Kiimbwanindi while till × mechanical weeding treatment combinations showed the lowest stem height at Ilonga site.

The combinations of pre-emergence weed control and post emergence weed control treatments did not significantly ($p>0.05$) affect the stem height at both sites. At Kiimbwanindi site, Oxfen × mechanical weeding treatment combination showed the highest stem height while Primagram × Force up herbicides' treatment combination showed the lowest stem height. At Ilonga site, Oxfen × Force up herbicide treatment combination showed the highest stem height while Oxfen × mechanical weeding treatment combination showed the lowest stem height.

Also, the application of tillage practice, pre-emergence herbicides and post emergence weed control treatment combinations did not significantly ($p>0.05$) increase the stem height at Kiimbwanindi. The till × Oxfen × mechanical weeding treatment combinations had the highest stem height followed by Till and ridge × Primagram × mechanical weeding. The lowest stem height was observed plants grown in till × Primagram ×

mechanical weeding treatment combination. At Ilonga site, weed control treatment combinations did not significantly ($p>0.05$) increase cassava stem height. Till and Ridge \times Oxfen \times Force up and Till and Ridge \times Oxfen \times Mechanical weeding led to the highest cassava stem height while till \times Oxfen \times Mechanical weeding led to the lowest stem height.

3.4.5.2 The influence of weed control treatment interactions on cassava plant stem girth at 5 months after planting

Table 3.6 shows the influence of weed control treatment interactions on cassava stem girth. At both sites, the combinations of tillage practices and pre-emergence weed control did not significantly ($p>0.05$) affect the stem girth. Till \times Oxfen treatment combinations led to the highest stem girth at Kiimbwanindi while Till and Ridge \times Oxfen treatment combinations, showed the highest stem girth at Ilonga site. Plots where till \times Primagram herbicide treatment combinations were applied showed the lowest stem girth for both sites.

The treatment combinations of tillage practices and post emergence weed control significantly ($p<0.05$) affect the stem girth at Kiimbwanindi site while did not significantly ($p>0.05$) affect the stem girth at Ilonga sites. Till and Ridge \times Mechanical weeding treatment combinations showed the highest stem girth at both sites. The plots where till \times Mechanical weeding treatment combinations were applied, showed the lowest stem girth at both sites.

The treatment combinations of pre-emergence and post emergence weed control did not significantly ($p>0.05$) affect the stem girth at both sites. At Kiimbwanindi site, Oxfen \times Force up herbicide treatment combinations showed the highest stem girth while

Primagram × Force up herbicides' treatment combinations showed the lowest stem girth. At Ilonga site, Oxfen × Force up herbicide treatment combinations showed the highest stem girth while Oxfen × Mechanical weeding treatment combinations showed the lowest stem girth.

The application of tillage practice, pre-emergence herbicides and post emergence weed control treatment combinations did not significantly ($p>0.05$) increase the cassava stem girth in both sites. At Kiimbwanindi site, cassava plants under the till × Oxfen × Force up and Till and Ridge × Primagram × Mechanical weeding treatment combinations had the highest stem girth while till × Primagram × Mechanical weeding treatment combination had the lowest stem girth. At Ilonga site, Till and Ridge × Oxfen × Force up and Till and Ridge × Oxfen × Mechanical weeding treatment combinations had the highest stem girth while cassava plants in till × Oxfen × Mechanical weeding treatment combinations had the lowest stem girth.

Table 3.6: The influence of weed control treatment interactions on cassava plant height and stem girth at 5 months after planting

Treatment interactions		Kiimbwanindi village		Ilonga village	
		Stem Height (cm)	Stem Girth (cm)	Stem Height (cm)	Stem Girth (cm)
A × B	Till × Oxfen	200.17a	10.58a	59.93a	6.58a
	Till × Primagram	182.08a	9.5a	64.2a	6.53a
	Till and Ridge × Oxfen	198.17a	10.02a	84.57a	7.67a
	Till and Ridge × Primagram	190.67a	10.35a	78.8a	7.38a
p value		<i>0.5461</i>	<i>0.1168</i>	<i>0.4789</i>	<i>0.7555</i>
A × C	Till × Force up	190.5a	10.63a	66.07a	7.05a b
	Till × Mechanical weeding	191.75a	9.45a	59.07a	6.07b 7.47a
	Till and Ridge × Force up	188.00a	9.48a	82.23a	b 7.58a
	Till and Ridge × Mechanical weeding	200.83a	10.88a	81.12a	7.58a
p value		<i>0.5093</i>	<i>0.0081</i>	<i>0.6248</i>	<i>0.1548</i>
B × C	Oxfen × Force up	193.83a	10.4a	75.87a	7.5a
	Oxfen × Mechanical weeding	204.5a	10.2a	68.63a	6.75a
	Primagram × Force up	184.67a	9.72a	72.43a	7.02a
	Primagram × Mechanical weeding	188.08a	10.13a	70.57a	6.9a
p value		<i>0.6783</i>	<i>0.4809</i>	<i>0.7033</i>	<i>0.4026</i>
A×B×C	Till × Oxfen × Force up	189.17a	11.3a	65.93a	7.33a
	Till × Oxfen × Mechanical weeding	211.17a	9.87a	53.93a	5.83a
	Till × Primagram × Force up	191.83a	9.97a	66.2a	6.77a
	Till × Primagram × Mechanical weeding	172.33a	9.03a	62.2a	6.3a
	Till and Ridge × Oxfen × Force up	198.5a	9.5a	85.8a	7.67a
	Till and Ridge × Oxfen × Mechanical weeding	197.83a	10.53a	83.33a	7.67a
	Till and Ridge × Primagram × Force up	177.5a	9.47a	78.67a	7.27a
	Till and Ridge × Primagram × Mechanical weeding	203.83a	11.23a	78.93a	7.5a
Mean		192.8	10.11	71.9	7.04
CV%		9	8.3	15.9	7
p value		<i>0.0633</i>	<i>0.8931</i>	<i>0.8515</i>	<i>0.5946</i>

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test, CV = coefficient of variation, A = Tillage practice, B = Pre emergence weed control treatment, C = Post emergence weed control treatment.

3.4.6 The influence of tillage practice, pre-emergence and post emergence weed control treatments on cassava yield, biomass and dry matter content

Results on the influence of tillage practices on cassava fresh root weight ($t\ ha^{-1}$), cassava biomass ($t\ ha^{-1}$) and cassava dry weight are shown in Table 3.7 below. At Kiimbwanindi

site, tillage practice did not significantly ($p>0.05$) influence the cassava fresh root weight and cassava biomass while significantly ($p\leq 0.05$) influenced the cassava dry weight. Till treatment showed the highest cassava fresh root weight, biomass and dry weight as compared to the till and ridge treatment which were used as standard.

The pre emergence and post emergence treatments did not significantly ($p>0.05$) affect the cassava fresh root weight, biomass and dry weight. Oxfen treatment led to highest cassava fresh root weight, biomass and lowest dry weight while mechanical weeding led to highest cassava fresh root weight, biomass and dry weight as compared to force up herbicide which showed the lowest cassava fresh root weight, biomass and dry weight even though it was used as the standard in post emergence weed control treatment.

At Ilonga site, tillage practice significantly ($p\leq 0.05$) influenced the cassava fresh root weight, cassava biomass and cassava dry weight respectively. Till and ridge treatment showed the highest cassava fresh root weight, biomass and dry weight. The pre-emergence and post emergence treatments did not significantly ($p>0.05$) affect the cassava fresh root weight, biomass and dry weight. Oxfen treatment showed the highest cassava fresh root weight, biomass and lowest dry weight for pre-emergence treatment while mechanical weeding led to lowest cassava fresh root weight, highest biomass and highest dry weight for post emergence treatment.

Table 3.7: The influence of tillage practice, pre-emergence weeds control and Post emergence weed control treatments on cassava yield, biomass and dry matter content

Treatment factors		Fresh root weight (t ha ⁻¹)	Cassava biomass (t ha ⁻¹)	Cassava dry weight (g)/ 500 g sample
Kiimbwanindi site				
Factor A (Tillage practice)	Till	38.56a	75.81a	199.17a
	Till and Ridge	36.61a	69.54a	159.58b
	<i>Mean</i>	37.59	72.68	179.38
	<i>p value</i>	0.6705	0.3332	0.0348
Factor B (Pre emergence treatment)	Oxfen	38.00a	74.19a	177.50a
	Primagram	37.17a	71.16a	181.25a
	<i>Mean</i>	37.59	72.68	179.38
	<i>p value</i>	0.8558	0.6352	0.8298
Factor C (Post emergence treatment)	Force up	34.53a	65.76b	173.33a
	Mechanical weeding	40.64a	79.59a	185.42a
	<i>Mean</i>	37.59	72.68	179.38
	<i>p value</i>	0.1944	0.0426	0.4914
Ilonga site				
Factor A (Tillage practice)	Till	8.2b	18.12b	144.58a
	Till and Ridge	21.14a	36.57a	194.58a
	<i>Mean</i>	14.67	27.35	169.58
	<i>p value</i>	0.0109	0.0211	0.0502
Factor B (Pre emergence treatment)	Oxfen	14.8a	27.7a	167.92a
	Primagram	14.55a	26.98a	171.25a
	<i>Mean</i>	14.68	27.34	169.59
	<i>p value</i>	0.9561	0.9214	0.8895
Factor C (Post emergence treatment)	Force up	14.85a	26.57a	164.58a
	Mechanical weeding	14.5a	28.11a	174.58a
	<i>Mean</i>	14.68	27.4	169.58
	<i>p value</i>	0.9391	0.8337	0.6775

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test

3.4.7 The influence of weed control treatment interactions on cassava fresh root weight, biomass and dry matter content

The results presented on Table 3.8 and Table 3.9 show the influence of weed control treatment interactions on cassava fresh root weight, biomass and dry matter content for both Kiimbwanindi and Ilonga sites, respectively. At both sites, the combinations of tillage practices and pre-emergence weed control treatments did not significantly ($p>0.05$) affect the cassava fresh weight, biomass and dry weight. At Kiimbwanindi site, Till \times Primagram treatment combinations showed the highest cassava fresh weight, biomass and dry weight. The till and Ridge \times Primagram herbicide treatment combinations showed the lowest cassava fresh weight and biomass while Till and Ridge \times Oxfen herbicide treatment combination showed the lowest cassava dry weight. At Ilonga site, Till and Ridge \times Oxfen treatment combinations showed the highest cassava fresh weight, biomass and dry weight while till \times Oxfen herbicide treatment combinations showed the lowest cassava fresh weight, biomass and dry weight.

At both sites, the treatment combination of tillage practices and post emergence weed control did not significantly ($p>0.05$) affect the cassava fresh weight, cassava biomass and cassava dry weight. At Kiimbwanindi site, Till and Ridge \times Mechanical weeding treatment combinations showed the highest cassava fresh weight and biomass while till \times Mechanical weeding treatment combinations showed the highest cassava dry weight. Also, Till and Ridge \times Force up herbicide treatment combinations showed the lowest cassava fresh weight, biomass and dry weight. At Ilonga site, Till and Ridge \times Force up herbicide treatment combinations showed the highest cassava fresh weight, while Till and Ridge \times Mechanical weeding treatment combination showed the highest cassava biomass and dry weight. Similarly, Till \times Force up herbicide treatment combinations showed the lowest cassava fresh weight, biomass and dry weight.

The treatment combinations of pre-emergence and post emergence weed control treatments did not significantly ($p>0.05$) affect the cassava fresh weight, biomass and dry weight at both sites. At Kiimbwanindi site, Oxfen × Mechanical weeding treatment combinations showed the highest cassava fresh weight and cassava biomass, while Primagram herbicide × Mechanical weeding treatment combinations showed the highest cassava dry weight. Also, Oxfen × Force up treatment combinations showed the lowest cassava fresh weight and dry weight, while Primagram × Force up treatment combinations showed the lowest cassava biomass.

The application of tillage practice, pre-emergence herbicides and post emergence weed control treatment combinations significantly ($p\leq 0.05$) affected both cassava fresh root weight and cassava biomass at Kiimbwanindi while did not at Ilonga site. At Kiimbwanindi site, Till and Ridge × Oxfen × Mechanical weeding treatment combinations gave the highest fresh root weight and biomass while Till and Ridge × Oxfen × Force up treatment combination recorded the lowest fresh root weight and biomass. At Ilonga site, Till and Ridge × Oxfen × Force up treatment combinations produced the highest fresh root weight and biomass while till × Oxfen × Mechanical weeding treatment combinations had the lowest fresh root weight and biomass.

Also, weed control treatment combinations did not significantly ($p>0.05$) affect the cassava dry matter content in both sites. Till × Primagram × Mechanical weeding, Till and Ridge × Oxfen × Mechanical weeding and Till and Ridge × Oxfen × Force up treatment combinations showed the highest cassava dry matter content at both sites. Till and Ridge × Oxfen × Force up and till × Oxfen × Force up treatment combinations gave the lowest dry matter content at both sites.

Table 3.8: The influence of weed control treatment combinations (interaction) on cassava fresh root weight, biomass and dry weight at Kiimbwanindi

Treatment interactions		Fresh root weight (t ha ⁻¹)	Cassava biomass (t ha ⁻¹)	Cassava dry weight (g)/500 g sample
A × B	Till × Oxfen	35.87a	71.74a	195.83a
	Till × Primagram	41.25a	79.87a	202.50a
	Till and Ridge × Oxfen	40.12a	76.64a	159.17a
	Till and Ridge × Primagram	33.08a	62.44a	160.00a
	<i>p value</i>	0.1876	0.0944	0.8672
A × C	Till × Force up	38.06a	72.38a	189.17a
	Till × Mechanical weeding	39.07a	79.23a	209.17a
	Till and Ridge × Force up	31.00a	59.14a	157.50a
	Till and Ridge × Mechanical weeding	42.21a	79.95a	161.67a
	<i>p value</i>	0.275	0.2826	0.6507
B × C	Oxfen × Force up	33.73a	66.20a	171.67a
	Oxfen × Mechanical weeding	42.27a	82.19a	183.33a
	Primagram × Force up	35.33a	65.32a	175.00a
	Primagram × Mechanical weeding	39.01a	76.99a	187.50a
	<i>p value</i>	0.5971	0.7355	0.9809
A×B×C	Till × Oxfen × Force up	40.10a	75.48a	186.67a
	Till × Oxfen × Mechanical weeding	31.64a	68.01a	205.00a
	Till × Primagram × Force up	36.01a	69.29a	191.67a
	Till × Primagram × Mechanical weeding	46.49a	90.46a	213.33a
	Till and Ridge × Oxfen × Force up	27.36a	56.92a	156.67a
	Till and Ridge × Oxfen × Mechanical weeding	52.90a	96.37a	161.67a
	Till and Ridge × Primagram × Force up	34.64a	61.36a	158.33a
	Till and Ridge × Primagram × Mechanical weeding	31.52a	63.53a	161.67a
Mean	37.58	72.68	179.4	
CV%	29.4	22.3	24.8	
<i>p value</i>	0.0179	0.0184	0.9428	

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test, CV = coefficient of variation, A = Tillage practice, B = Pre emergence weed control treatment, C = Post emergence weed control treatment.

Table 3.9: The influence of weed control treatment combinations (interaction) on cassava fresh root weight, biomass and dry weight at Ilonga

Treatment interactions		Fresh root weight (t ha ⁻¹)	Cassava biomass (t ha ⁻¹)	Cassava dry weight (g)/500 g sample
A × B	Till × Oxfen	5.91a	16.24a	132.5a
	Till × Primagram	10.49a	19.99a	156.67a
	Till and Ridge × Oxfen	23.68a	39.16a	203.33a
	Till and Ridge × Primagram	18.6a	33.97a	185.83a
	<i>p value</i>	0.2983	0.5448	0.3906
A × C	Till × Force up	7.86a	16.75a	142.5a
	Till × Mechanical weeding	8.54a	19.48a	146.67a
	Till and Ridge × Force up	21.83a	36.39a	186.67a
	Till and Ridge × Mechanical weeding	20.45a	36.74a	202.5a
	<i>p value</i>	0.8209	0.8717	0.808
B × C	Oxfen × Force up	17.37a	31.63a	163.33a
	Oxfen × Mechanical weeding	12.22a	23.78a	172.5a
	Primagram × Force up	12.32a	21.51a	165.83a
	Primagram × Mechanical weeding	16.77a	32.44a	176.67a
	<i>p value</i>	0.3013	0.2116	0.9723
A×B×C	Till × Oxfen × Force up	9.17a	20.63a	123.33a
	Till × Oxfen × Mechanical weeding	2.66a	11.86a	141.67a
	Till × Primagram × Force up	6.55a	12.87a	161.67a
	Till × Primagram × Mechanical weeding	14.43a	27.1a	151.67a
	Till and Ridge × Oxfen × Force up	25.58a	42.62a	203.33a
	Till and Ridge × Oxfen × Mechanical weeding	21.79a	35.7a	203.33a
	Till and Ridge × Primagram × Force up	18.09a	30.15a	170.00a
	Till and Ridge × Primagram × Mechanical weeding	19.11a	37.79a	201.67a
Mean	14.67	27.34	170	
CV%	59.8	54.1	33	
<i>p value</i>	0.6014	0.7735	0.5342	

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test, CV = coefficient of variation, A = Tillage practice, B = Pre emergence weed control treatment, C = Post emergence weed control treatment.

3.4.8 Relationship between cassava growth parameters and cassava fresh root weight at Ilonga site

The relationship between cassava growth parameters and cassava fresh root weight is shown in Table 3.10. The correlation analysis revealed that, there was a highly significant, strong positive relationship ($r = 0.925$, $p < 0.001$) between the cassava stem height and the cassava fresh root weight. Also, there was a significant strong positive relationship ($r = 0.781$, $p < 0.05$) between the cassava stem girth and the cassava fresh root weight.

Table 3.10: Correlation analysis between cassava growth parameters and cassava fresh root weight at Ilonga site

	Stem girth	Stem height	Fresh root weight
Stem girth	1		
Stem height	0.916***	1	
Fresh root weight	0.781*	0.925***	1

n = 24, df =n-2, *Significant correlation p = 0.05, Significant correlation p = 0.01 and ***Significant correlation p = 0.001

3.4.9 Relationship between cassava growth parameters and cassava fresh root weight at Kiimbwanindi

The results on the relationship between cassava growth parameters and cassava fresh root weight are shown in Table 3.11. The correlation analysis showed that, there was a non-significant positive relationship ($r = 0.389$, $p > 0.05$) between the cassava stem height and the cassava fresh root weight. Also, there was non-significant positive relationship ($r = 0.055$, $p > 0.05$) between the cassava stem girth and the cassava fresh root weight.

Table 3.11: Correlation analysis between cassava growth parameters and cassava fresh root weight at Kiimbwanindi site

	Stem girth	Stem height	Fresh root weight
Stem girth	1		
Stem height	0.452	1	
Fresh root weight	0.055	0.389	1

n = 24, df =n-2, *Significant correlation p = 0.05, Significant correlation p = 0.01 and ***Significant correlation p = 0.001

3.4.10 Comparison of cassava fresh root weight (tha^{-1}) and fresh biomass between Ilonga and Kiimbwanindi sites

The comparison between cassava fresh root weight (t ha^{-1}) and fresh biomass across sites was conducted to see if there is a statistical difference in the studied areas. A paired-samples t-test was conducted to evaluate the effect of the weed control treatment

combinations on cassava fresh root weight at Ilonga site (mean = 14.6725 t ha⁻¹) and Kiimbwanindi site (mean = 37.5825 t ha⁻¹). The two tailed results showed a highly significant difference ($t(7) = -5.73966$, $p = 0.000706$) in cassava fresh root weight between the two sites. Also, two tailed results for the cassava biomass weight at Ilonga site (mean = 27.34 t ha⁻¹) and Kiimbwanindi site (mean = 72.6775 t ha⁻¹) showed a highly significant difference ($t(7) = -6.87252$, $p = 0.000237$) in cassava biomass weight between the two sites.

3.4.11 Influence of tillage practice, pre-emergence and post emergence weed control options on soil pH, N, P, K, Ca and Mg nutrient

Results from the study revealed that, the selected weed control treatment combinations had not significantly affected soil pH, amount of N, P, K, Ca and Mg nutrients at both sites.

3.5 Discussion

3.5.1 Effect of tillage practice, pre-emergence and post emergence weed control options to weeds growth

a) Effect of tillage practice and herbicide use as pre-emergence weed control options to weeds growth

The current study findings revealed that, till + ridge × primagram gold (a.i 290 g/L S-metolachlor and 370 g/L atrazine) as a pre-emergence weed control herbicide significantly hinders the growth of weed for a long period of time up to 53 and 47 days after planting at Kiimbwanindi and Ilonga sites, respectively. This could possibly be due to the reason that ridges burring weed seeds below the surface and the combination of 290 g/L S-metolachlor and 370 g/L atrazine kills the exposed seedlings or shoots of germinating weeds before emergence or shortly after emergence. Similar findings were

reported by Schwartz-Lazaro and Copes (2019) who observed that, weed seedbank and weed population is highly reduced when the frequency of tillage increases as a result it exposes weed seeds to the conditions that do not favor growth. Also, Godwin *et al.* (2017) reported pre-emergence herbicides help in controlling weeds up to four weeks after cassava planting. The only weeds managed to grow after pre-emergence herbicides application were *Asclepias syriaca*, *Trichodesma zeylanicum*, *Commelina benghalensis*, *Cyperus rotundus*, *Mucuna pruriens*, *Ocimum sp*, *Echinochloa colona*, *Cynodon species*, *Dactyloctenium aegyptium*, *Digitaria sp*, *Portulaca oleracea*, *Reissantia sp*. This was probably due to their reproductive ability to reproduce both sexually and asexually and their adaptive ability to grow in a wide range of soil.

b) Effect of mechanical weeding and herbicide use as post emergence weed control options to weeds growth

For the plots where mechanical weeding was done, more than three weeding operations were required due to the presence of perennial weeds. This could be due to the ability of perennial weeds (*Cyperus rotundus*, *Cynodon species* and *Lonicera sp*) to regrow faster as compared to annual weeds as the mechanical weeder only killed the above ground plant parts while the below parts remained alive. Other researchers have shown that, more than two weeding operations are required for effectively control of perennial weeds (Ekeleme *et al.*, 2019). For those plots where glyphosate was applied as post emergence weed control treatment, weeds were significantly controlled because glyphosate is a systematic, non-selective herbicide therefore it kills all grown weeds during the time of its application. Udensi *et al.* (2012) reported that, herbicide use in ridged farm was more efficient in controlling weeds as compared to the use of mechanical weeder.

3.5.2 Influence of weed control treatments on cassava plant height and stem girth at 5 months after planting

The results showed that, the combination of tillage, pre-emergence and post emergence weed control treatments had influence on cassava plant height and girth. This might be due to the fact that, as the combination of these treatments reduce competition of soil nutrient and sunlight hence the cassava grows and expand with vigor. Similar results were reported by Velmurugan *et al.* (2017) that weed management activities affect the growth of cassava stem and girth. Also, Schwartz-Lazaro and Copes (2019) and Kraehmer *et al.* (2014), showed tillage helps root penetration by loosening the compacted soils and exposes the underground weed seeds to the direct sunlight thus helping the crop to grow and the application of herbicides control weeds that emerged at the time of application or those weed already emerged thus the crop planted in a weed free soil.

3.5.3 Relationship between cassava growth parameters and cassava fresh root weight

Results showed that, at Kiimbwanindi site, there was a non-significant positive relationship between the cassava stem height and the cassava fresh root weight, $r = 0.389$, $p > 0.05$. Also, there was non-significant positive relationship between the cassava stem girth and the cassava fresh root weight, $r = 0.055$, $p > 0.05$. At Ilonga site, there was a highly significant strong positive relationship between the cassava stem height and the cassava fresh root weight, $r = 0.925$, $p < 0.001$. There was a significant strong positive relationship between the cassava stem girth and the cassava fresh root weight, $r = 0.781$, $p < 0.05$. This profound effect of growth parameter of cassava on the final tuber yield could be due to the fact that, growth parameters tend to show a significant positive contribution to the tuber weight at a maximum vegetative phase of cassava. During this stage, the increase in cassava height and girth goes in accordance to the increase in cassava fresh root weight. Similar results were reported by Edet *et al.* (2015); Amarullah

et al. (2017); Misganaw and Bayou (2020) who observed the increase in stem height and girth is positively correlated with the increase in fresh root weight and dry matter yield. This occurs at the maximum vegetative phase of cassava.

Also, the non-significant relationship between the cassava growth and yield parameters at Kiimbwanindi site is likely attributed to the high sand proportion of soil at the studied field which favors excessive increase in cassava roots as compared to silty clay loam soil found at Ilonga (Table 3.1). These results were also reported by Onasanya *et al.* (2021), which indicated that on light-textured soil, there is highly increase in cassava root yield. Another possible explanation for this varied response is the difference in cumulative rainfall amount received during growing season at these sites which could possibly affect the growth of cassava plants hence affect root expansion. Similar results were also reported by Misganaw and Bayou (2020); Onasanya *et al.* (2021), who reported environmental variation between sites could affect cassava growth and root yield.

3.5.4 Comparison of cassava fresh root weight (tha^{-1}) and fresh biomass between

Ilonga and Kiimbwanindi sites

There was a significant difference observed in fresh root weight and biomass of cassava between two sites that may be attributed to the difference in soil characteristics and weather condition during 2019/2020 planting season. At Ilonga there were high rainfall which was not suitable for cassava growth as compared to Kiimbwanindi site. The high rainfall intensity and distribution usually lead to poor roots formation thus affecting the cassava fresh root weight and its biomass. These results are in agreement with that of Ntawuruhunga and Dixon, (2010), who reported that there was a positive influence of optimum rainfall on root yield of many cassava varieties, particularly during the first 4-6 months of growth.

Additionally, the difference in soil characteristics between the two sites could be another reason contributing to the huge difference in fresh root yield and biomass obtained as it was observed that, at Ilonga site, the soil texture was Silt clay loamy which gives inadequate room for the cassava root expansion as compared to the loamy sand texture found at Kiimbwanindi site. These results were similar to that of Onasanya *et al.* (2021), who indicated that light-textured soil had high cassava root yield compared to soils with high clay content. Also, other soil nutrients at Ilonga site were high above the suitable nutrient range for cassava production thus it ought to cause the toxicity effect toward cassava growth and root formation. Nutrient like Calcium found to be $10.8 \text{ cmol}_c\text{kg}^{-1}$ while the suitable range for cassava production is between 1.0 and $5.0 \text{ cmol}_c\text{kg}^{-1}$ thus this could cause the toxicity effect to root yield and cassava growth obtained. The similar results were explained by Howeler, (2002) who explained excess nutrient in the soil could cause reduction in cassava performance as the example of excess Calcium content in the soil reduces cassava root and shoot growth.

3.6 Conclusion and Recommendations

The study concludes that integrated/combination of weed management option is more effective in controlling weeds in cassava production than the use of single treatment. Results showed the combination of till + ridges, appropriate application of pre-emergence herbicides Primagram Gold (a.i 290 g/L S-metolachlor + 370 g/L atrazine) or Oxfen (a.i Oxyfluorfen 24% EC) and post emergence herbicides Force up (a.i 480 g/L of Glyphosate-Isopropylamine salt) provided significant favourable environment for cassava growth and root formation as compared to the use of mechanical weeding alone.

Thus, it is recommended that, proper tillage and ridging before cassava planting, use of pre-emergence herbicide made of S-metolachlor and atrazine and proper use of

glyphosate as post emergence herbicide could highly help keeping cassava farms free from weed for a longer period of time as compared to other treatment combinations. Also, further studies should be conducted on the residue effect of continuous application of herbicides in cassava plant and roots produced.

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CHAPTER FOUR

4.0 COST-BENEFIT ANALYSIS OF THE SELECTED WEED CONTROL OPTIONS IN CASSAVA PRODUCTION SYSTEM

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4.1 Abstract

Weed control is one of the major constraints in cassava production as it requires high capital and it takes 50 to 80 percent of the total production budget. Based on this fact, there is a need to determine the most economical integrated weed control option(s) that will effectively control weeds and minimize cost of production. The effect of different weed control treatment combinations was studied and the most economical one(s) were determined during 2019/2020 planting season at Ilonga village, Kilosa district and Kiimbwanindi village, Mkuranga district, Tanzania. Till only and till + Ridge, pre-emergence herbicides (Primagram Gold a.i 290 g/L S-metolachlor + 370 g/L atrazine and Oxfen a.i Oxyfluorfen 24% EC), post emergence herbicides (Force up a.i 480 g/L of Glyphosate-Isopropylamine salt and back pack weeder with modified tines were tested on Cassava variety Kiroba in a (2 × 2 × 2) factorial experiment arranged in a randomized complete block design (RCBD) replicated three times. Data collected included all variable costs for the inputs applied on each weed control treatment combination, costs of cassava harvest and the price of cassava per kilogram, and data were subjected to benefit-cost ratio analysis. Results revealed that, at Kiimbwanindi site, till × Oxfen × Force up and till × Primagram × Force up treatment combinations had a high benefit cost ratio of 2.39 and

2.04, respectively, while at Ilonga site, Till and Rigde × Oxfen × Force up treatment combination had high benefit cost ratio of 2.31 and high cassava root yield of 25.58 t/ha. These high benefit cost ratios indicate feasibility of using respective weed control combinations in cassava production from the economic point of view. Thus, good farm preparation, the use of *Oxyfluorfen 24% EC* herbicides as pre-emergence herbicide and *480 g/L of Glyphosate-Isopropylamine salt* as post emergence weed control treatments should be encouraged in cassava production.

Keywords: *Cassava, Weed, Investment cost, Integrated weed control option(s), Benefit cost ratio*

4.2 Introduction

Weed control has been identified as one of the major constraints in cassava production systems as it requires high capital, and found to take 50 to 80% of the total budget while its return on investment (ROI) ranging from 32% to 37% (Ekeleme *et al.*, 2016; Rana and Rana, 2016; Ojiako *et al.*, 2018). Due to that, Ekeleme *et al.* (2019) reported that weed infestation can lead to 50-90% cassava yield loss if did not properly managed. Therefore, in order to maximize profit through reducing the cost of weeding operation, weeds should be controlled by the least expensive available technology that will effectively control weeds without affecting other phases of cassava production (Rana and Rana, 2016).

There is a need to determine the most cost-effective integrated weed control options by considering all the required input operational costs under different tested weed control options. In addition, the fundamental economic principles for weed management should be observed (Wiles, 2004; De Rus, 2010). According to Wiles, (2004) and Ekeleme *et al.* (2019) who reported that, the economic threshold for weed management is calculated by comparing the value of prevented yield loss from weed competition in the current season with the cost of an input's application (Wiles, 2004; Ekeleme *et al.*, 2019). Thus, any weed control measures should be used only when its results are expected to be more economically beneficial than without using any control measure (Rana and Rana, 2016). The cost of weed control can be defined as the value of the resource used in producing the materials used for weed control in their best alternative aiming at either maximizing output, maximizing profit, maximizing utility, minimizing cost or a combination of all these (Ettah and Angba, 2016).

For the determination of good integrated weed control option, the choice of weed control inputs to use depends not only on its efficacy but also on its cost. Thus, in order to work

out the most profitable treatment, the economics of each treatment should be worked out on the basis of current market prices of the inputs and output obtained (Rana and Rana, 2016). This can be done by conducting the cost-benefit analysis (CBA) which is a systematic approach to estimate the short- and long-term consequences by measuring all costs and all possible profits and benefits from an investment project proposal taking into account both quantitative and qualitative factors (Rana and Rana, 2016). Cost benefit analysis can be done by calculating the benefit cost ratio (BCR), by which if the ratio obtained is above one meaning that the farmer would get more additional returns from investment.

In Eastern zone of Tanzania, adoption of the best integrated weed control option(s) on cassava production which lead to the maximum return while having the lowest cost as possible thus producing highest profit has not been clearly done, thus farmers still face challenges in terms of efficiency, timeliness and effectiveness in weed control as they mostly rely on a single weed control option (Kayeke *et al.*, 2018). Due to that cassava fresh root yield in Tanzania was estimated by FAOSTAT (2017) to be 6.2 t ha⁻¹ which is far most below the production potential of about 50.8 – 80 t ha⁻¹ (Senkoro *et al.*, 2018; URT, 2020). Other researchers reported the benefit cost analysis of a single agricultural input like fertilizer only as its used in cassava production (Senkoro *et al.*, 2018). Therefore, the aim of this study was to establish the cost of inputs used at each stage of production and to establish the most economical integrated weed management option(s) tested in cassava production in the selected sites of Eastern zone of Tanzania.

4.3 Material and Method

4.3.1 Description of the study site

The study was conducted at Ilonga, Kilosa district, Morogoro region (6°46' 27" S, 37°2'14" E, and 479.95 m ASL) and Mkuranga, Coastal region (7°12'19" S, 39°20'38" E, 93.87 m ASL). At Mkuranga, average monthly temperature ranges from a low of around 18.8 °C during the coolest months of July and August when maximum temperatures are 29.4 °C and 29.7 °C respectively, to the highest monthly means of 31.9 °C to 32.6 °C during the hot season from December to March, when the temperatures drop to only 23.7 °C to 24.5 °C during that period. Relative humidity ranges from 67-70 % from August to October, increasing to 82 % during the wettest months of April. The average annual rainfall is 1 073 mm (ranging from 585 mm to 1 536 mm). Mkuranga experiencing bi-modal rainfall pattern; March to May (main wet season) with about 550 mm of rain and November to December (short rains) with 235 mm of rain (Mkuranga, 2009; RCO, 2011). At Kilosa, the district experiences an average of eight months of rainfall (October to May), with the highest levels between February and March. The rainfall distribution is bimodal in good years, with short rains (October to January), followed by long rains (mid-February to May). Mean annual rainfall ranges between 1 000 and 1 400 mm in the southern flood plain, while further north (Gairo Division) has an annual rainfall ranging from 800 to 1,100 mm. The mean annual temperature in Kilosa is about 25°C (Kajembe *et al.*, 2013; Zakayo, 2015).

4.3.2 Experimental layout and Treatments

Experimental design used was factorial experiment (2 × 2 × 2) arranged in randomized complete block design, whereby eight plots were established to make one replication. Plot size was 20 m² (4 m × 5 m) and plots were separated by 1 m and replication was separated by 2 m. Treatments were replicated three times in each site. Treatments were two tillage

practices (Till only and till + Ridge), two pre-emergence weed control options (herbicide) (Primagram Gold a.i 290 g/L S-metolachlor and 370 g/L atrazine and Oxfen a.i Oxyfluorfen 24% EC) and two post emergence weed control options (herbicide; Force up a.i 480 g/L of Glyphosate-Isopropylamine salt and mechanized weeder tool; back pack weeder with modified tines). Pre emergence weed control treatment was applied during a day of planting. Post emergence weed control treatments were applied when weed population reached 30% (three to four leaves stage) within a plot as per IITA (ACAI project) protocol. Cassava (Kiroba variety) planted at a population of 10,000 plants/ha was used.

4.3.3 Data collection

Data on inputs and its costs per tested weed management option/treatment were collected, which included the costs of purchasing herbicides and planting materials, labour costs on land preparation, tillage and ridging, herbicide application, physical weeding, and cassava harvesting. Also, data on the market price of cassava per kilogram were recorded for each site. The market price (September 2020) was obtained from farmers who sold cassava in local markets and District Extension Workers.

4.3.4 Data analysis

Data on costs of acquiring herbicides, planting materials, labor costs on land preparation, tillage and ridging, herbicide application, mechanical weeding, cassava harvesting were recorded and used to compute benefit cost ratio.

Definition of terms

Production costs: Production cost refers to the value of inputs used in producing a product or output. In agricultural production, there are two types of costs; fixed cost

which is the cost that does not change as output changes over a period of time and variable costs which are the costs that keep on changing as the output changes at the production period (Igben and Eyo, 2002; Itam *et al.*, 2018).

Marginal return: Marginal return is the difference between the gross farm income (total revenue) and total variable cost. It is often used to estimate the cost and return associated with the business concerned. It is expressed as;

$$MR = TR - TVC$$

Where; MR is the Marginal return, TR is the total revenue obtained by multiplying the quantity of cassava yield harvested per hectare by the price of one kilogram of the cassava product, TVC is the Total Variable Cost which is the summation of all variable cost incurred (Itam *et al.*, 2018; Daramola *et al.*, 2019).

Cost benefit analysis: Cost benefit analysis (CBA) is a systematic approach to estimate the short- and long-term consequences by measuring all costs and all possible revenue and benefits from treatments applied at a period of production taking into account both quantitative and qualitative factors (Rana and Rana. 2016). According to De Rus (2021) state that the cost benefit analysis can be done using the benefit cost ratio. Thus, for this study, the benefit cost ratio (B:C) for each treatment applied was calculated by dividing gross profit by the total cost of weed control methods.

$$Benefit\ Cost\ Ratio = \frac{Marginal\ returns\ (MR)}{Total\ variable\ cost\ (TVC)}$$

If the $B:C < 1$ then the costs exceed the benefit, therefore the tested weed control package will be rejected. However, if the $B:C \geq 1$ then the benefits exceed the costs, therefore the tested weed control package will be accepted.

4.4 Results

4.4.1 The influence of tillage practice, pre-emergence and post emergence weed control treatments on cassava fresh root weight (t/ha) at Kiimbwanindi and Ilonga sites

The results on the influence of tillage practices on cassava fresh root weight (t ha^{-1}) are shown in Table 4.1 below. At Kiimbwanindi site, tillage practice did not significantly ($P>0.05$) influence the cassava fresh root weight. Till treatment showed the highest cassava fresh root weight of 38.56 t ha^{-1} as compared to the till and ridge treatment which was used as standard. Pre emergence treatments and post emergence treatments did not significantly ($P>0.05$) affect the cassava fresh root weight. Oxfen herbicide which was as a pre-emergence weed control treatment exhibited the highest cassava fresh root weight (38 t ha^{-1}) while mechanical weeding which was the post emergence weed control treatment led to highest cassava fresh root weight (40.64 t ha^{-1}) followed by force up herbicide which exhibited the lowest cassava fresh root weight (34.53 t ha^{-1}).

At Ilonga site, tillage practice significantly ($P<0.05$) influenced the cassava fresh root weight. Till and ridge treatment resulted into the highest cassava fresh root weight of 21.14 t ha^{-1} . Pre emergence treatments and post emergence treatments did not significantly ($P>0.05$) affect the cassava fresh root weight. Oxfen treatment showed the highest cassava fresh root weight (14.8 t ha^{-1}) when used as a pre-emergence treatment while mechanical weeding which was used as a post emergence treatment led to lowest cassava fresh root weight (14.5 t ha^{-1}) as compared to force up herbicide which exhibited the highest cassava fresh root weight (14.85 t ha^{-1}).

Table 4.1: The influence of tillage practice, pre-emergence weeds control and post emergence weed control treatments on cassava fresh root weight

Treatment factors		Fresh root weight (t ha ⁻¹)
Kiimbwanindi		
Factor A (Tillage practice)	Till	38.56a
	Till and Ridge	36.61a
	<i>Mean</i>	37.59
	<i>p value</i>	0.6705
Factor B (Pre emergence treatment)	Oxfen	38.00a
	Primagram	37.17a
	<i>Mean</i>	37.59
	<i>p value</i>	0.8558
Factor C (Post emergence treatment)	Force up	34.53a
	Mechanical weeding	40.64a
	<i>Mean</i>	37.59
	<i>p value</i>	0.1944
Ilonga		
Factor A (Tillage practice)	Till	8.2b
	Till and Ridge	21.14a
	<i>Mean</i>	14.67
	<i>p value</i>	0.0109
Factor B (Pre emergence treatment)	Oxfen	14.8a
	Primagram	14.55a
	<i>Mean</i>	14.68
	<i>p value</i>	0.9561
Factor C (Post emergence treatment)	Force up	14.85a
	Mechanical weeding	14.5a
	<i>Mean</i>	14.68
	<i>p value</i>	0.9391

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test

4.4.2 The influence of weed control treatment interactions on cassava productivity

The results presented on Table 4.2 show the influence of weed control treatment interactions on cassava fresh root weight for both Kiimbwanindi and Ilonga sites. At both sites, the combinations of tillage practices and pre-emergence weed control treatments did not significantly ($P > 0.05$) affect the cassava fresh weight. At Kiimbwanindi site, Till \times Primagram treatment combinations showed the highest cassava fresh weight of 41.25 t ha⁻¹ while Till and Ridge \times Primagram herbicide treatment combinations showed the lowest cassava fresh weight of 33.08 t ha⁻¹. At Ilonga site, Till and Ridge \times Oxfen treatment

combinations showed the highest cassava fresh weight of 23.68 t ha⁻¹ while till × Oxfen herbicide treatment combinations showed the lowest cassava fresh weight of 05.91 t ha⁻¹.

At both sites, the treatment combination of tillage practices and post emergence weed control did not significantly ($P>0.05$) affect the cassava fresh weight. At Kiimbwanindi site, Till and Ridge × Mechanical weeding treatment combinations showed the highest cassava fresh weight of 42.21 t ha⁻¹ while Till and Ridge × Force up herbicide treatment combinations showed the lowest cassava fresh weight of 31.00 t ha⁻¹. At Ilonga site, Till and Ridge × Force up herbicide treatment combinations showed the highest cassava fresh weight of 21.83 t ha⁻¹, while till × Force up herbicide treatment combinations showed the lowest cassava fresh weight of 07.86 t ha⁻¹.

The treatment combinations of pre-emergence weed control and post emergence weed control treatments did not significantly ($P>0.05$) affect the cassava fresh weight at both sites. At Kiimbwanindi site, Oxfen × Mechanical weeding treatment combinations showed the highest cassava fresh weight of 42.27 t ha⁻¹ while Oxfen × Force up treatment combinations showed the lowest cassava fresh weight of 33.73 t ha⁻¹.

The application of tillage practice, pre-emergence herbicides and post emergence weed control treatment combinations significantly ($P<0.05$) affected cassava fresh root weight at Kiimbwanindi while did not at Ilonga site. At Kiimbwanindi site, Till and Ridge × Oxfen × Mechanical weeding treatment combinations gave the highest fresh root weight (52.9 t ha⁻¹) while Till and Rigde × Oxfen × Force up treatment combination recorded the lowest fresh root weight (27.36 t ha⁻¹). At Ilonga site, Till and Rigde × Oxfen × Force up treatment combinations produced the highest fresh root weight (25.58 t ha⁻¹) while till

× Oxfen × Mechanical weeding treatment combinations had the lowest fresh root weight (2.66 t ha⁻¹).

Table 4.2: The influence of weed control treatment combinations (interaction) on cassava fresh root weight at Kiimbwanindi and Ilonga

Treatment interactions		Fresh root weight (tha-1)	
		Kiimbwanindi i	Ilonga
A × B	Till × Oxfen	35.87a	5.91a
	Till × Primagram	41.25a	10.49a
	Till and Ridge × Oxfen	40.12a	23.68a
	Till and Ridge × Primagram	33.08a	18.6a
	<i>p value</i>	0.1876	0.2983
A × C	Till × Force up	38.06a	7.86a
	Till × Mechanical weeding	39.07a	8.54a
	Till and Ridge × Force up	31.00a	21.83a
	Till and Ridge × Mechanical weeding	42.21a	20.45a
	<i>p value</i>	0.275	0.8209
B × C	Oxfen × Force up	33.73a	17.37a
	Oxfen × Mechanical weeding	42.27a	12.22a
	Primagram × Force up	35.33a	12.32a
	Primagram × Mechanical weeding	39.01a	16.77a
	<i>p value</i>	0.5971	0.3013
A×B× C	Till × Oxfen × Force up	40.10a	9.17a
	Till × Oxfen × Mechanical weeding	31.64a	2.66a
	Till × Primagram × Force up	36.01a	6.55a
	Till × Primagram × Mechanical weeding	46.49a	14.43a
	Till and Ridge × Oxfen × Force up	27.36a	25.58a
	Till and Ridge × Oxfen × Mechanical weeding	52.90a	21.79a
	Till and Ridge × Primagram × Force up	34.64a	18.09a
	Till and Ridge × Primagram × Mechanical weeding	31.52a	19.11a
Mean	37.58	14.67	
CV%	29.4	59.8	
<i>p value</i>	0.0179	0.6014	

Values in the same column, followed by the same letter(s) do not differ significantly ($P \leq 0.05$) according to Tukey's honestly significance test, CV = coefficient of variation, A = Tillage practice, B = Pre emergence weed control treatment, C = Post emergence weed control treatment.

4.4.3 Cost benefit assessment of weed control treatment combinations on cassava productivity in Kiimbwanindi and Ilonga

The cost of inputs used in the production of cassava, total variable cost, gross return, and net income for cassava production at Kiimbwanindi and Ilonga sites are shown in Table

4.3 and Table 4.4, respectively. In this study, the same market prices of cassava were used (the market estimate for the cassava in September 2020 was Tanzania shillings 80 000 per tonne of fresh cassava and Tanzania shillings 100 000 per tonne of fresh cassava at Kiimbwanindi and Ilonga, respectively) for the budget estimation for all treatments applied in the studied sites. It was observed that, total variable cost per hectare varied from 947 000 Tanzania shillings for the inputs used on the treatments till × primagram × force up and treatments till × oxfen × force up to 2 072 900 Tanzania shillings for the inputs used under the treatments till and ridge × oxfen × mechanical weeding Tanzania shillings at Kiimbwanindi site, while at Ilonga site, total variable cost ranged from Tanzania shillings 522 000 for the inputs used on the treatments combination till × primagram × force up to 1 636 900 Tanzania shillings for the inputs used under the treatments Till and ridge × oxfen × mechanical weeding and treatments combination till and Ridge × primagram × mechanical weeding.

The gross revenue per hectare obtained differed from one treatment to the other at both sites. At Kiimbwanindi site, the highest gross revenue was 4 232 000 and the lowest was 2 188 480 while at Ilonga site, the highest gross revenue was 2 558 00 and the lowest was 266 000. Thus, at Kiimbwanindi site the treatment combinations of till × Oxfen × Force up and till × Primagram × Force up treatment combinations had high benefit cost ratio of 2.39 and 2.04, respectively, regardless of the lower cassava root yield obtained from those treatment combinations while at Ilonga site, the only treatment combination Till and Ridge × Oxfen × Force up had higher benefit cost ratio of 2.31.

Table 4.3: The partial budget analysis showing the cost, gross revenue, marginal revenue* and benefit-cost ratio of different weed management options in Kiimbwanindi site

	ACTIVITY	PRICE PER Ps	VARIABLE COSTS/ Ha	TREATMENTS									
				1. Till + Primagram + Force up	2. Till + Primagram + Mechanical weeding	3. Till + Oxfen + Force up	4. Till + Oxfen + Mechanical weeding	5. Till and Ridge + Primagram + Force up	6. Till and Ridge + Primagram + Mechanical weeding	7. Till and Ridge + Oxfen + Force up	8. Till and Ridge + Oxfen + Mechanical weeding		
Input Cost	Primagram purchase	12000	36000	36000	36000			36000	36000			36000	36000
	Oxfen purchase	12000	36000			36000	36000					36000	36000
	Force up purchase	12000	36000	36000		36000	36000	36000	36000			36000	36000
	Mechanical weeder purchase	450000	450000		450000		450000			450000			450000
Labor cost of operation	Tillage	100000	250000	250000	250000	250000	250000	250000	250000	250000	250000	250000	250000
	Ridging	150000	375000					375000	375000	375000	375000	375000	375000
	Planting	50000	125000	125000	125000	125000	125000	125000	125000	125000	125000	125000	125000
	Pre emergence weed control	25000	62500	62500	62500	62500	62500	62500	62500	62500	62500	62500	62500
	1st Post emergence weed control using mechanical weeder	50000	125000					125000			125000		125000
	Fuel costs/ Ha (Avg 21 lts/ Ha)	1800	37800			37800		37800			37800		37800
	1st Post emergence weed control using herbicide	25000	62500	62500		62500			62500			62500	
	2nd Post emergence weed control using mechanical weeder	50000	125000					125000			125000		125000
	Fuel costs/ Ha (Avg 21 lts/ Ha)	1800	37800			37800		37800			37800		37800
	2nd Post emergence weed control using herbicide	25000	62500	62500			62500			62500		62500	
	3rd Post emergence weed control using mechanical weeder	50000	125000					125000			125000		125000
	Fuel costs/ Ha (Avg 21 lts/ Ha)	1800	37800			37800		37800			37800		37800
	3rd Post emergence weed control using herbicide	25000	62500	62500			62500			62500		62500	
	4th Post emergence weed control			125000	125000	125000	125000	125000	125000	125000	125000	125000	125000
	Harvest cost		50000	125000	125000	125000	125000	125000	125000	125000	125000	125000	125000
	TOTAL VARIABLE COST (TVC)				947000	1661900	947000	1697900	1322000	2036900	1322000	2072900	
REVENUE	A. Cassava price/ t	80000		80000	80000	80000	80000	80000	80000	80000	80000	80000	
	B. Tonnes of Cassava harvested per Ha			36.011	46.489	40.1	31.644	34.644	31.522	27.356	52.9		
GROSS REVENUE (GR)				2880880	3719120	3208000	2531520	2771520	2521760	2188480	4232000		
MARGINAL REVENUE (MR) = GR - TVC				1933880	2057220	2261000	833620	1449520	484860	866480	2159100		
BENEFIT-COST RATIO (BCR) =(MARGINAL REVENUE/ TOTAL VARIABLE COST)				2.04	1.24	2.39	0.49	1.10	0.24	0.66	1.04		

* The cost, gross revenue, marginal revenue was in Tanzanian shillings. The market cassava market price was estimated in September 2020. Herbicide spraying costs involves the cost of knapsack sprayer used and water.

Table 4.4: The partial budget analysis showing the cost, gross revenue, marginal revenue* and benefit-cost ratio of different weed management options in Ilonga site

	ACTIVITY	PRICE PER P _s	VARIABLE COSTS/Ha	TREATMENTS									
				1. Till + Primagram + Force up	2. Till + Primagram + Mechanical weeding	3. Till + Oxfen + Force up	4. Till + Oxfen + Mechanical weeding	5. Till and Ridge + Primagram + Force up	6. Till and Ridge + Primagram + Mechanical weeding	7. Till and Ridge + Oxfen + Force up	8. Till and Ridge + Oxfen + Mechanical weeding		
Input Cost	Primagram purchase	12000	36000	36000	36000			36000	36000				
	Oxfen purchase	12000	36000			36000		36000				36000	36000
	Force up purchase	12000	36000		36000		36000		36000			36000	
	Mechanical weeder purchase	450000	450000			450000	450000	450000		450000			450000
Labor cost of operation	Tillage	50000	125000	125000	125000	125000	125000	125000	125000	125000	125000	125000	125000
	Ridging	100000	250000						250000	250000	250000	250000	250000
	Planting	10000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000	25000
	Pre emergence weed control	5000	12500	12500	12500	12500	12500	12500	12500	12500	12500	12500	12500
	1st Post emergence weed control using mechanical weeder	50000	125000			125000		125000		125000			125000
	Fuel costs/Ha (Avg 21 lts/Ha)	1800	37800			37800		37800		37800			37800
	1st Post emergence weed control using herbicide	5000	12500	12500		12500			12500			12500	
	2nd Post emergence weed control using mechanical weeder	50000	125000			125000		125000		125000			125000
	Fuel costs/Ha (Avg 21 lts/Ha)	1800	37800			37800		37800		37800			37800
	2nd Post emergence weed control using herbicide	5000	12500	12500		12500			12500			12500	
	3rd Post emergence weed control using mechanical weeder	50000	125000			125000		125000		125000			125000
	Fuel costs/Ha (Avg 21 lts/Ha)	1800	37800			37800		37800		37800			37800
	3rd Post emergence weed control using herbicide	5000	12500	12500		12500			12500			12500	
	4th Post emergence weed control	50000	125000	125000	125000	125000	125000	125000	125000	125000	125000	125000	125000
	Harvest cost		50000	125000	125000	125000	125000	125000	125000	125000	125000	125000	125000
	TOTAL VARIABLE COST (TVC)				522000	1386900	522000	1386900	772000	1636900	772000	1636900	1636900
REVENUE	A. Cassava price/t	100000		100000	100000	100000	100000	100000	100000	100000	100000	100000	
	B. Tonnes of Cassava harvested per Ha			6.55	14.43	9.17	2.66	18.09	19.11	25.58	21.79		
GROSS REVENUE (GR)				655000	1443000	917000	266000	1809000	1911000	2558000	2179000		
MARGINAL REVENUE (MR) = GR - TVC				133000	56100	395000	-1120900	1037000	274100	1786000	542100		
BENEFIT-COST RATIO (BCR) =				0.254789272	0.040449924	0.75670498	-0.80820535	1.343264249	0.167450669	2.313471503	0.331174782		

* The cost, gross revenue, marginal revenue was in Tanzanian shillings. The market cassava market price was estimated in September 2020.

Herbicide spraying costs involves the cost of knapsack sprayer used and water.

4.5 Discussion

4.5.1 The influence of tillage practice, pre-emergence weed control and post emergence weed control treatments on cassava yield

The study findings revealed that, cassava yield per hectare observed in Till and Ridge × Oxfen × Mechanical weeding treatment combination and in Till and Ridge × Oxfen × Force up treatment combination for Kiimbwanindi and Ilonga, respectively, could be attributed to the fact that ridges provided large surface area for the cassava roots to grow in vigor and enlarge more, also the oxfen herbicide (a.i Oxyfluorfen 24% EC) reduces the weed competition during the initial stages of cassava growth. These results are in accordance to that of Schwartz-Lazaro and Copes (2019) who observed, weed seedbank and weed population is highly reduced as tillage intensity increases as a result of exposure of weed seeds to the conditions that does not favour their growth. Also, Godwin *et al.* (2017), reported pre-emergence herbicide help in controlling weeds for up to four weeks after cassava planting.

4.5.2 Cost benefit assessment of weed control treatment combinations on cassava yield in Kiimbwanindi and Ilonga

Results show that, the variation in total variable costs between treatments inputs applied could be attributed to the different amount of input applied and difference in method used. The results are in accordance to that of Kosemani and Bamgboye (2018) who observed that there were differences in expenditure per hectare during cassava production whereby the difference were attributed to the amount of biological energy input, chemical energy input and difference in method of equipment acquisitions in cassava production. Also, James *et al.* (2011) observed in cassava production, the amount spent on manual resources was the highest as compared to the amount spent on chemical resources as the amount spent in manual resources was more than 42% of the total cost of the inputs.

Additionally, the gross revenue per hectare obtained indicated there were difference between treatments tested at both sites. This difference in revenue observed was largely attributed to the differences in cassava productivity obtained per treatment. Similar results were reported by Velmurugan *et al.* (2017), that during cassava production, the differences in cassava growth and the cassava productivity may be attributed to the difference in weed management options applied.

Thus, at Kiimbwanindi site the treatment combinations of till × Oxfen × Force up and till × Primagram × Force up treatment combinations had higher benefit cost ratio of 2.39 and 2.04, respectively, regardless of the lower cassava root yield obtained from those treatment combinations while at Ilonga site, the only treatment combination Till and Ridge × Oxfen × Force up which had higher benefit cost ratio of 2.31. These results were due to the fact that, the use of herbicides to control weeds in cassava is cheaper than the use of mechanical weeding treatments. The results are in agreement with that of Udensi *et al.* (2012); Islami *et al.* (2017); Kosemani and Bamgboye (2018) and Ekeleme *et al.* (2019) who reported that the use of herbicides in controlling weeds in cassava production was very cheap as compared to the use of other means of weed control like mechanized tools.

4.6 Conclusion and Recommendations

Benefit cost ratio of 2.31 at Ilonga site and 2.39 at Kiimbwanindi site, respectively indicates feasibility of using integrated herbicides and mechanical means for cassava production from the economic point of view. Thus, good farm preparation, the use of herbicides, the use of high yield cassava varieties (Kiroba) and optimum use of fertilizer increased the profitability of cassava production. Based on the findings of this study, tillage should be done before cassava planting, and proper use of pre-emergence

herbicides and post-emergence herbicides (glyphosate) as integrated weeding operations could lead to optimum cassava root production. Therefore, the treatment combinations of Till and Ridge × Oxfen herbicide × Force up herbicide and till × Oxfen herbicide × Force up herbicide are recommended for Ilonga and Kiimbwanindi sites respectively in order to increase cassava productivity and income of the farmers in these areas.

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CHAPTER FIVE

5.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study concludes that, perennial weeds *Cyperus rotundus*, *Echinochloa colona*, *Trichodesma zeylanicum*, *Reissantia sp*, *Mucuna pruriens* and *Commelina benghalensis* are the mostly common and abundantly occurring weed species with intrinsic adaptive characteristics compared to other species in cassava fields in Eastern zone Tanzania.

The integrated weed management options are more effective in controlling weeds in cassava production than the use of single management option. Results showed the combination of till + ridges, appropriate application of pre-emergence herbicides Primagram Gold (a.i 290 g/L S-metolachlor + 370 g/L atrazine) or Oxfen (a.i Oxyfluorfen 24% EC) and post emergence herbicides Force up (a.i 480 g/L of Glyphosate-Isopropylamine salt) provided significant favorable environment for cassava growth and root formation as compared to the use of mechanical weeding alone.

Also, the integrated treatment options of Till and Ridge × Oxfen herbicide × Force up herbicide which had the highest benefit cost ratio (2.31) for Ilonga site at Kilosa district and till × Oxfen herbicide × Force up herbicide which had the benefit cost ratio of 2.39 for Kiimbwanindi site at Mkuranga district indicates feasibility of cassava production from the economic point of view.

5.2 Recommendations

The results suggest that, the integration of proper tillage and ridging before cassava planting, use of pre-emergence herbicide made of S-metolachlor and atrazine and proper use of glyphosate as post emergence herbicide should be used in weed control in cassava production as it led to highest cassava yield with highest cost-benefit ratio.

Also, further studies should be conducted on regular basis to identify possible weed population shifts and the residue effect of continuous application of herbicides S-metolachlor + atrazine, Oxyfluorfen and Glyphosate-Isopropylamine salt herbicides on both cassava plants and roots produced, physical and chemical properties of the soil, also the effect of continuously use of mechanical weeding season after season in the soil's physical and chemical properties.

APPENDICES

Appendix 1: Other Weeds found in the selected cassava farms during the 2019/2020 season at Ilonga, Kilosa district and Kiimbwanindi, Mkuranga district in Eastern Zone of Tanzania

Sn	Scientific Name	Family	Life Cycle
1	<i>Agaricus</i> sp	Agaricaceae	Annual
2	<i>Amaranthus viridis</i> L.	Amaranthaceae	Annual
3	<i>Celosia trigyna</i> L.	Amaranthaceae	Erect annual plant
4	<i>Annona senegalensis</i>	Annonaceae	Perennial
5	<i>Asclepias syriaca</i>	Apocynaceae	Perennial
6	<i>Acanthospermum hispidum</i>	Asteraceae	Branched annual plant
7	<i>Ageratum conyzoides</i> L.	Asteraceae	Annual plant
8	<i>Bidens Pilosa</i> L.	Asteraceae	Annual plant
9	<i>Conyza</i> sp	Asteraceae	Annual plant
10	<i>Emilia javanica</i> L.	Asteraceae	Annual herb
11	<i>Kleinia</i> sp	Asteraceae	Perennial herbs
12	<i>Launaea cornuta</i>	Asteraceae	Herbaceous perennial plant
13	<i>Tridax procumbens</i> L.	Asteraceae	Annual, sometimes perennial
14	<i>Markhamia obtusifolia</i>	Bignoniaceae	Perennial
15	<i>Trichodesma zeylanicum</i>	Boraginaceae	Annual plant
16	<i>Reissantia</i> sp	Celastraceae	Perennial
17	<i>Gloriosa superba</i> L.	Colchicaceae	Perennial
18	<i>Commelina benghalensis</i> L.	Commelinaceae	Herbaceous perennial plant,
19	<i>Bonamia mossambicensis</i>	Convolvulaceae	Perennial
20	<i>Ipomoea</i> sp	Convolvulaceae	Perennial
21	<i>Jacquemontia</i> sp	Convolvulaceae	Perennial
22	<i>Merremia tridentate</i> L.	Convolvulaceae	Perennial herb
23	<i>Cucumis</i> sp	Curcubitaceae	Perennial plant
24	<i>Cyperus rotundus</i>	Cyperaceae	Perennial
25	<i>Kylinga erecta</i>	Cyperaceae	Creeping perennial glabrous sedge
26	<i>Acalypha ciliate</i>	Euphorbiaceae	Annual herb
27	<i>Euphorbia heterophylla</i> L.	Euphorbiaceae	Annual plant
28	<i>Euphorbia hirta</i> L.	Euphorbiaceae	Annual herb
29	<i>Phyllanthus amarus</i>	Euphorbiaceae	Annual plant
30	<i>Mucuna pruriens</i>	Fabaceae	Annual
31	<i>Senna hirsuta</i> L.	Fabaceae	Herbaceous perennial shrub
32	<i>Tephrosia</i> sp	Fabaceae	Perennial
33	<i>Cenchrus mitis</i>	Gramineae	Annual crop
34	<i>Cynodon dactylon</i> L.	Gramineae	Perennial grass
35	<i>Cleodendrum johnstonii</i>	Lamiaceae	Perennial
36	<i>Ocimum</i> sp	Lamiaceae	Perennial
37	<i>Cassia mimosoides</i> L.	Leguminaceae	Annual, or short-lived perennial herb
38	<i>Corchorus aestuan</i> L.	Malvaceae	Annual or perennial herb
39	<i>Corchorus olitoris</i> L.	Malvaceae	Annual or biennial herb
40	<i>Hibiscus surattensis</i> L.	Malvaceae	Climbing annual plant
41	<i>Melochia corchorifolia</i> L.	Malvaceae	Spreading perennial plant
42	<i>Waltheria indica</i> L.	Malvaceae	Perennial plant
43	<i>Corchorus olitorius</i>	Malvaceae	Annual
44	<i>Boerhavia diffusa</i> L.	Nyctaginaceae	Herbaceous perennial plant
45	<i>Boerhavia erecta</i> L.	Nyctaginaceae	Erect annual to perennial plant
46	<i>Cynodon nlemfuensis</i>	Poaceae	Perennial
47	<i>Cynodon plectostachyus</i>	Poaceae	Perennial
48	<i>Dactyloctenium aegyptium</i>	Poaceae	Annual

49	<i>Digitaria</i> sp	Poaceae	Annual
50	<i>Echinochloa colona</i>	Poaceae	Annual
51	<i>Portulaca oleraceae</i> L.	Portulacaceae	Annual
52	<i>Agathisanthemum bojeri</i>	Rubiaceae	Shrubby perennial herb
53	<i>Richardia scabra</i> L.	Rubiaceae	Annual plant
54	<i>Spermacoce pusilla</i>	Rubiaceae	Prostrate annual
55	<i>Tecca leontopetaloides</i> L.	Teccaceae	Perennial herb
56	<i>Lantana camara</i> L.	Verbenaceae	Perennial
57	<i>Tribulus terrestris</i> L.	Zygophyllaceae	Annual plant
