EFFECTS OF WEED DENSITY AND SPECIES DIVERSITY ON CASSAVA (*Manihot esculenta* Crantz) YIELD IN ZAMBIA

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A DISSERTATION SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCINCE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

Cassava (*Manihot esculenta* Crantz) is one of the important crops in the world for food and income security. Cassava production is challenged by weeds as they reduce yield to 100%. Effective weed management in cassava production depend determination of weed species diversity and determination of Critical Period for Weed Removal (CPWR). A study was conducted in Zambia, to document weed species diversity in cassava growing areas of Chongwe and Kaoma districts in Zambia, determine the critical period for weed removal in three cassava varieties (Nalumino, Mweru and Chila) commonly grown and estimate yield losses caused by weeds on cassava farms in the two districts. Farmer survey was done to get farmers experience in weed management. The experiment was established whereby, two weeding regimes were applied; weed free (WF) and weed infested (WI). Sampling of weeds for density, species diversity and yield components was done within the period of 21 days until 168 Days After Planting (DAP). Weed species diversity index in Kaoma was 2.12 and Chongwe was 3.487 (Shannon diversity index) Forty weed species in Chongwe and 33 in Kaoma were identified. Findings reveal that CPWR was between 42 and 105DAP. Cassava root yield 6 months after planting in weed free plots was significantly higher than in weed infested treatments. All varieties were affected by weeds, and under un controlled weed condition the loss of 99.9% was recorded. Therefore, keeping the crop weed free during the first four months of growth is important for all varieties in order to reduce significant yield penalty. Additionally, further studies on weed seed bank and herbicide screening is important to postulate appropriate weed management and reduce drudgery respectively.

Key words: critical period for weed removal, weed management; weeds in cassava, cassava yield loss, weed species diversity.

DECLARATION

I, JOSEPH JULIUS NZUNDA, 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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Prof. K. P. Sibuga Date
(Supervisor)

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This dissertation is dedicated to my unforgettable beloved late Mother Lena Halinga who laid the foundation of my education and for her nurture to this level of achievements but could not live to see me to this end.

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LIST OF ABBREVIATIONS AND SYMBOLS

CEC	Cation Exchange Capacity
Cm	Centimetre
CPWC	Critical period for Weed Control
CPWR	Critical period for Weed Removal
CV	Coefficient of Variation
DAP	Days After Planting
FAO	Food and Agriculture Organization
Fig.	Figure
GoT	Government of Tanzania
HI	Harvest index
IITA	International Institute of Tropical Agriculture
Kg	Kilogram
LA	Leaf Area
LAI	Leaf Area Index
M	Metre
m.a.s.l.	Metre above sea level (altitude)
mm	Millimetre
RCBD	Randomized Complete Block Design
REP	Replication
RIL	Research Information Limited (Ltd)
SPSS	Statistical Packages for Social Science
SUA	Sokoine university of Agriculture
t ha^{-1}	Tonne per hectare
WF	Weed Free
WI	Weed Infested
ZARI	Zambia Agriculture Research Institute

CHAPTER ONE

1.0 INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is one of the important crops in the world as it serves several purposes such as food security, trade, industrial raw material and source of livestock feed. The crop constitutes an important part of the diets for not less than a billion people, majority of whom are poor. It provides a source of livelihood and is becoming a crop millions of people in Africa, Asia and Latin America depend on (FAO, 2001; Ntawuruhunga *et al*., 2013 and IITA, 2013). Cassava ranks sixth staple in the world after rice, wheat, maize, potato and sweet potato (Kanju *et al.*, 2016). Cassava as a food security crop, is drought resistant, has high productivity (30% to 100% higher calorie production per unit of labour and land than maize). Cassava serves as a source of livelihood to about 300 million people in sub-Saharan Africa (IITA, 2013) and major source of energy for more than 200 million people (Melifonwu, 1994). Cassava is grown in 39 African countries and it is the second most important staple food crop in Sub-Saharan Africa (Agahiu *et al*., 2012). In Zambia, cassava ranks second after maize (Rusike, 2009) and it is estimated that about half as many households produce cassava as compared to those which produce maize (Nielson, 2009).

Cassava production is challenged by weed infestation, amongst the major biotic problems. Weeds are plants that are characterized with pernicious and persistence in hindering the growth of the cultivated plants. Weeds reduce yield and the resultant loss can be as high as 100% when not controlled. Weed control in cassava in the humid tropics is much more demanding when compared to other crops because weeds grow abundantly and vigorously

than cassava (IITA, 2014; Rodenburg and Johnson, 2009 and IITA, 2000). Weeds grow more vigorously and rapidly because of the heat and higher light intensity in the tropics than in Europe and America (RIL, 2011). The study was conducted in Zambia to determine weed density and species diversity, critical period for weed competition and effects of weed infestation on cassava yield. The period when the weed competition is high is the time when there are significant yield losses, therefore it is the time when control or removal of weeds is necessary; in this case the terms critical period for weed removal and critical period for weed control mean the same and are directly linked to critical period for weed competition.

1.1 Justification

Weed infestation is a major constraint in cassava production in Africa (Gianessi, 2013) and it is a major factor explaining low crop yield (Agumagu *et al.,* 2008 and Soares *et al.,* 2016). In Zambia, many farms record an average of 30% yield reduction. Some farmers lose entire crops due to heavy weed infestation (Gianessi, 2009). Weed control in cassava is much more demanding both in labour and time as compared to other crops (IITA, 2014). Women contribute more than 90% of the hand-weeding labour while 69% of farm children between the ages of 5-14 are forced to leave school and engage in weeding, thus affecting their education (IITA, 2014).

The critical period of weed competition as well as intensity of competition must be established in order to plan appropriate and economic weed management program (Silva, *et al.,* 2013). Weeds behave differently in crops (Zimdahl, 2007) and therefore the yield

losses due to weed crop competition depend on dominant weed species, their density and cover percentage (Hassannejad and Ghafarbi, 2013).

The expected output of the study was to generate database to be used in planning weed management Programmes and understanding weed diversity, critical period for weed removal and yield loss caused by weeds because most lists of weeds available were not done on cropping systems basis (Melifonwu, 1994).

1.2 Objectives

1.2.1 Overall objective

Estimation of weed density and species diversity and their effects on cassava yield in cassava growing areas of Chongwe and Kaoma Districts in Zambia for documentation purposes and recommendation of best weed management period.

1.2.2 Specific objective

i. To establish weed species diversity in cassava growing areas of Chongwe and Kaoma districts in Zambia.
ii. To determine the critical period for weed removal in three cassava varieties commonly grown in the two districts, and
iii. To estimate yield losses caused by weeds on cassava farms in the two districts.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Effects of Weeds in Crops

Weeds affect crops through different ways such as competition for environmental resources and impairing crop quality. These effects result into low yield leading to financial losses to farmers and it is explained that they are the most universal of all crop pests, proliferating each year on every farm in Africa (Gianessi, 2009; RIL, 2011). Crops have many pests, but weeds are the most common and most important pest that need control in all Agro-climatic zones in worldwide (Sibuga, 1997 and Agahiu *et al.,* 2012).

According to Gianessi (2013) and FAO (2013), the average cassava yields produced by smallholder farmers is ranging from 6 -12.8 t ha^{-1} across Africa i.e., 8.7 t ha^{-1} for central Africa, 6.7 t ha^{-1} for east Africa, 9 t ha^{-1} for western Africa and 10 t ha^{-1} for southern Africa; this yield is low compared to the potential yield of cassava which is 80 t ha^{-1}. Low yield is due to the increase in weed population which diverts available resources from crop communities; for example, 1 kg increase in weed dry matter causes a loss of 1 kg loss in crop dry matter (Hasanuzzaman, 2015). This means that, the more the density of weeds in the farm the more the loss is encountered. The degree of interference of weeds on crops depends on several factors including, the weed community structure, the environment and the period in which they coexist (Soares *et al.*, 2016). The degree of this competition depends on the species, the population density and mainly, the period in which they remain growing together. Research has shown that weed management causes an average yield gap of 5 tons/ha (Gianessi, 2013), furthermore, the report by Silva *et al.*

(2013) support that weed competition at initial stages of cassava development are among major factors contributing to the low income.

The work of Chikoye and Ekeleme (2001), reported that cassava yield in weeded areas was significantly higher than in plots with weeds. Additionally, when cassava was intercropped with corn and maize in the forest/savanna transition of Nigeria, the yield of cassava was two to five times higher in weeded areas than weedy plots. This shows that weeds have direct effect in cassava production, and need to be studied in different environment because weed effects differ depending on environment, for example there was an increase of 47.6% of weed fresh biomass in treatments applied with fertilizer, implying that application of fertilizer to cassava favour growth of weed and increase its competitiveness (Soares, 2016).

It was also reported by FAO (2013) that in East Africa for example, weeds have severe impact on production as compared to insect pests and diseases, and the effect on yield reduction is about 50%. Another experience is shown by Soares *et al*. (2016) whereby cassava reduced in productivity by 51% when weeding was done after 70 days of coexistence with the crop. Weeds have numerous challenges, other scientists reported that the yield losses in farmers' fields ranges from 25% to total crop failure because farmers could not perform necessary weeding at the optimal time (Sibuga,1999; Vissoh *et al*., 2004; Fofana and Rauber, 1999; Chikoye *et al*., 2005) cited by Gianessi (2009).

In Zambia, one of the challenges in cassava production is low yield at farm level compared to potential yields of improved varieties (Kabwe, 2014). The low yields are

attributable to many factors and weeds are among them. Weeds are a major contributing factor to the reduction of yields in Zambia, many farms record yield reduction averaging 30% (Masole and Kasalu, 1997) as cited by Gianessi (2009). On top of yield loss, weeding is time consuming and it is an activity which takes many days in the field than any other activity (Nhamo, 2007). An example, within one cropping season in Zambia, the estimated time which was spent for weeding was in the range of 90 -120 days (Gianessi, 2009). Furthermore, according to Lebot (2009), weeding requires between 20 and 200 man-days per hectare which is one of the highest costs in crop production.

2.2 Critical Period for Weed Control

In view of problems associated with weeds, the attention and planning for control remains crucial. To have a proper weed management plan, the critical period for weed control (CPWC) for a particular crop need to be known. The critical period is the shortest time span in the crop growth cycle when weeding will result in highest economic returns (Hasanuzzaman, 2015); in other words, it is the span of time between seeding or emergence when weed competition does not reduce crop yield and after which weed competition will lead to reduced crop yields (Knezevic *et al.,* 2002). In addition, it is a period in the crop growth cycle during which weeds must be controlled to prevent yield loss. It is also stated by Knezevic (2002) that, during the crop growth cycle, there is a phase in which weeds must be prevented to control crop losses, such a period is described as Critical period for weed control The crop may remain in the field with weeds for a certain period without causing significant yield losses, but if it stays long it may result to yield losses. This critical period of weed competition also recognized as the critical period of weed control or removal (A'ihi *et al*., 2017) is therefore showing the most influencing

phase of weed competition and if weeds are removed at this period, unacceptable losses are escaped.

It has been suggested that cassava is in general susceptible to weed interference during the first 10 to 16 weeks after planting because of slow canopy development for ground cover and weed suppression (Gianessi, 2013). However, this study included an analysis of the critical period for weed removal in respect to species of the weeds available in cassava growing areas in Zambia. The critical period in relation to proper weeding time differs from one crop variety to another depending on the phenology, branching characteristics and leaf area index. Thus, determination of Critical period for weed control is a key component of integrated weed management and it is useful for making decision on the need for and timing of weed control (Silva *et al.*, 2013 and Knezevic, 2002).

According to FAO (2013), the full canopy has the effect of smothering weeds and therefore reducing crop weed competition, therefore in order to get reasonable yield, cassava should be free from weeds for the period prior to full canopy development

Similar work by Agumagu *et al.* (2008) and Soares *et al.* (2016) reported that weed is the major problem and main factor that affect cassava crop yield; and in cassava weeding should start 3 weeks after planting and be repeated as necessary up to the time when canopy develops and cover (Lebot, 2009). The same scientist (Lebot, 2009), reported that, weed competition during the first 2 months can reduce yield to 50% and therefore weeding after 4 months does not necessarily increase yield significantly.

2.3 Weed Density and Species Diversity

Apart from determining the critical period for weed removal as the initial steps toward planning for weed management, the identification of the most frequent weed species is necessary because, each one according to the potential to establish in the area and the aggressiveness can interfere differently with the cassava plant (Soares *et al.*, 2016). However, very few studies have linked the determination of Critical period for weed removal, weed species density and diversity.

The study of weed density is helpful in determining how the species population changes over time in response to agronomic practices. In the management of agricultural land, accurate estimation of the variables is very important especially when improving productivity and conserving biodiversity (Nkoa *et al*., 2015). Since identification of weed species can be the basis for their management, effective weed management programs will rely on accurate information on the systematic of weeds, their frequency, uniformity, density, coverage, and growth habit (Hassannejad and Ghafarbi, 2013). Understanding the inherent taxonomic diversity in weeds is a primary need in weed management and identification of weeds interfering with crop production is a critical step in integrated weed management. This includes correct identification of the weed species and species-group, activities which were conducted during this study.

Weed species diversity relates to the number of weed species present in an ecosystem. Weed diversity can be viewed in terms of population that may differ due to weed management effects (Dekker, 1997). However, the knowledge on different weed flora is needed in order to postulate an appropriate weed management strategy for the farmers in Africa (Adesina, 2012). Moreover, sustainable weed management systems demand that,

weed diversity be understood so that comprehensive strategies can be developed to either reduce their opportunities, or to avoid the economic crop losses resulting from them.

2.4 Cassava Yield Losses

Cassava is highly susceptible to competition with weeds, and the yield losses may be as high as 90-100% depending on duration of competition and weed management practices adopted (Silva, 2013). In order to minimize such losses and increase cassava production in the tropics, weed control is the cornerstone. With appropriate weed control measures and all agronomic practices, cassava potential yields can reach 80 tonnes per hectare, compared to the current world average yield of just 6-12.8 tonnes/ha (FAO, 2013). It is essential to estimate losses caused by weeds to facilitate the process of making decision regarding the level of infestation that can be allowed in the field.

This study paid attention to both weed species dominant in cassava growing areas and the weed density and abundance in cassava growing areas, and estimated cassava yield losses caused by weeds. The study evaluated the depressive effects of weeds on cassava during the early growth up to six months, a period within which full cassava canopy development is expected. The study also made prediction and estimation of losses of crop production due to co-existence with weeds; it determined the optical levels or control periods of weeds. This research benefits both the farmers and agricultural researchers involved in planning for best weed control management.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Sites

The study was conducted between October 2016 and June 2017 at three locations (1) at IITA-Zambia research farm in Chongwe district and (2) at ZARI-Longe experimental farm in Kaoma district and (3) on farmers' fields in Kaoma district in Western Province, Zambia. The geographical coordinates at Longe in Kaoma is S14^{0}8', E 24^0.9', 1163.3 m.a.s.l. and in Chongwe district from the IITA experimental farm is S15^0.3', E 28^{0}3' and 1188.6 m.a.s.l. The two sites differ in terms of soils and rainfalls, Kaoma experiences more rainfall (902.4 mm) than Chongwe (813 mm) of precipitation falls annually. Kaoma soils are predominantly well-drained sandy loam (65%) with varying topsoil depth of 100–150 mm in the relatively flat uplands (World bank ,2016) while soils in Chongwe are sandy loam.

3.2 Soil Sampling

Soil sampling was done in Kaoma district at Longe Agricultural station and in Chongwe district at Kabangwe, the IITA Experimental farm. Marking was done to identify the field for taking soil samples. The field was divided into the 6 equal portions each 1000 m^2. A zig-zag pattern on each portion was followed in identifying sampling points (Fig.1). Samples were taken at every 10 metres.

The sampling point was first cleaned to remove vegetation and mulch. At each point, a one-kilogram sample was collected from a rectangular soil slice 20 cm deep and 5cm

thick. The sample was placed in a plastic paper bag and labelled to show the place where sample were obtained, the name of the farm and date of sampling.

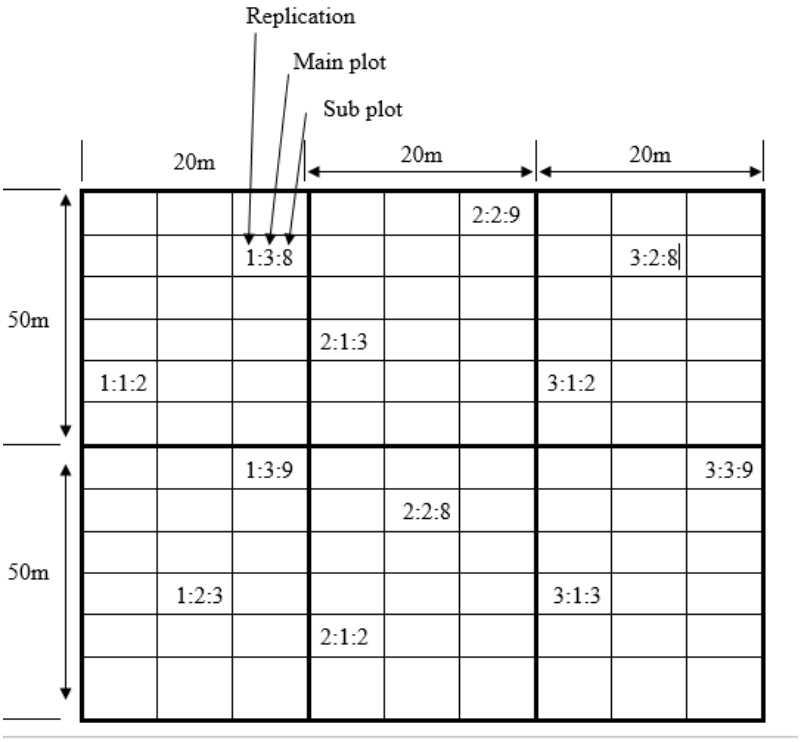

Figure 1: Map of the field showing points where soil sample were taken

Key for sample bag label: Number in the box

3.2.1 Mixing of the soil and preparation of soil samples for analysis

The soil sub-samples from representative points were placed in a clean container and mixed thoroughly by a spade and 2 kg of soil was placed into labelled bags. The soils were air dried, sieved at a 2-mm sieve, properly packed, labelled and taken to Zambia Agriculture Research Institute (ZARI) the laboratory for analysis.

3.2.2 Soil analysis

Soil samples were analysed at ZARI (Zambia Agriculture Research Institute) laboratory.

Analysis aimed at determination of the following Soil Properties: Calcium, Magnesium (NH_4OAc) pH 7.00, Potassium, Sodium (NH_4OAc) pH 7.00, Available Phosphorus (Bray 1), pH ($CaCl_2$), or (H_2O) or (KCl), Total Nitrogen (Kjeldahl), Organic carbon (Walkley black), Zinc, Iron, Cation Exchange Capacity (CEC) and Particle size (% Sand, % Silt and % Clay). The determination of Phosphorus was done by Spectrophotometry Bray 1-P, pH by the electrometric method, Nitrogen by Kjeldahl Technique, Organic carbon by Walkley-black method, Calcium, Magnesium, Potassium and Sodium by Ammonium Acetate Extraction (Appendix 6).

3.3 Weather Data

Rainfall and temperature data were collected during the research period (October 2016 - June 2017) relying on rain gauge and thermometer installed at ZARI-Longe Agriculture Station and IITA experimental field. Temperature data for Kaoma were obtained from the weather station installed at Longe by GeoSUN Africa (a consulting Engineering company that offers a broad range of services and products relating to solar resource assessments and modelling, mainly in Sub-Saharan Africa.

3.4 Farmer Survey

A farmer survey was conducted in Kaoma to collect information related to effects of weeds in cassava, how farmers manage weeds in their cassava fields and to identify fields for assessment of weed species composition. The selection of farmers was done randomly basing on the list of farmers who are within the camps (sampling frame), areas and village surrounding the experimental site (Longe). The list was obtained from the camps extension officers. Selected farmers were those who grow cassava and had fields with the

history of cassava production. Farmers were interviewed by enumerators (Agriculture Extension officers and ZARI staff) according to a structured questionnaire (Appendix 1). The total number of 81 farmers from within Mukandamina and Longe camps were interviewed. Mukandamina and Longe are in Kaoma. Data from the Survey was subjected to analysis using Statistical Package for the Social Science (SPSS). Descriptive analysis was performed, and the results were summarized and presented in graphs and tables.

3.5 Weed Sampling and Data Collection for Weed Density and Species Diversity

(a) Kaoma

Determination of weed density and diversity involved collection and identification of weed species from fields that had cassava cropping history for at least one season within a period of one year but fallowed during research season. The sampling frame comprised 10 fields each holding 200 square meters from which 10 samples of weeds were collected using a 0.25 sq. quadrat and making a total of 100 samples. Sampling of weeds was conducted by throwing a Quadrat at 5 m in a zigzag pattern (Fig. 2). All weeds within each quadrat (10 weed sample) were uprooted manually, collected and weighed. Important parameters taken included type of weed species (Botanical Name and Family), Number of each species per sampling unit, weed biomass (Fresh weight) and dry weight. Species were identified by botanical and Family names (this was achieved by comparing weed parts and descriptions in the weed identification books, considering shape, colour, architecture of leaves, panicles, stem and fruits. Unidentified species representatives were carefully taken, placed between paper, labeled by writing the location, serial number of the field and the sample/species, placed in the weed presser and sent to ZARI (Zambia Agricultural Research Institute) Herbarium for further identification. Samples were dried in the oven for 48 hours under 80^0C following the procedure outlined by Chikoye *et al.* (2008) to determine dry weight.

(b) Chongwe

Data for weed density and species diversity were collected from the experimental field whereby the selected field was divided into 10 sub fields each measuring 81 m^2. Weed samples were collected, identified as per section 3.5 above

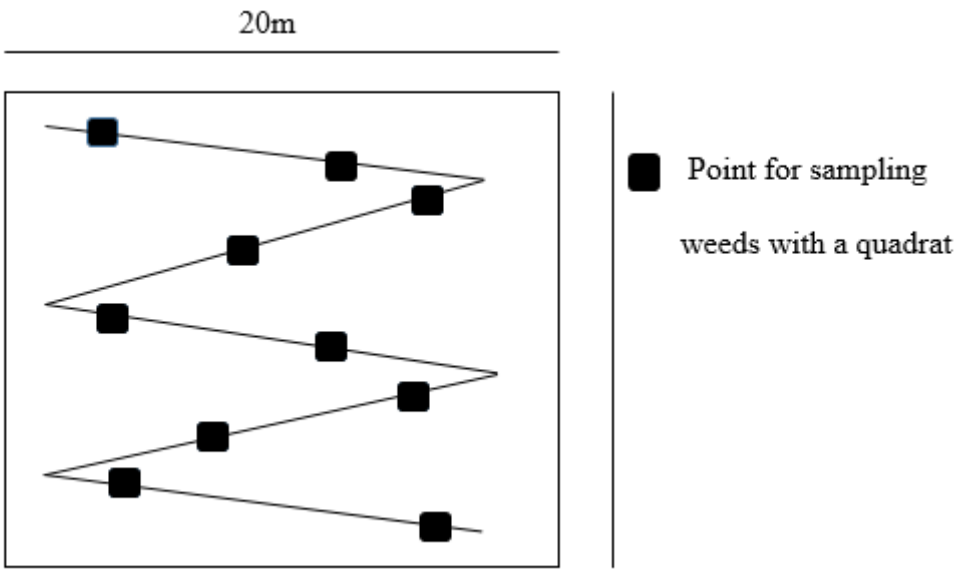

Figure 2: Field lay out showing sampling pattern

3.6 Weed density and Diversity Data Analysis

Weed density indices were summarized using quantitative measurements as originally described by Thomas (1985) for assessing weeds in fields. Shannon-Wiener was used for weed diversity (appendix 2). The number of weeds from each quadrat were used to calculated weed density per square metres. Data concerning weed number, density and

biomass were subjected to GenStat statistical package for analysis of variance. Weed biomass from weed free plots and weed infested plots were compared using T-test.

3.7 Land Preparation

The experimental farm was cleared before establishment of the trial. The land was prepared by ploughing and harrowing using a tractor.

3.8 Preparation of Planting Materials

Cassava planting materials were prepared from three varieties namely Nalumino (branching architecture variety), Mweru (upright architecture) and Chila (semi-branching variety). Cuttings of 30 cm long for each of the varieties were prepared for planting and the total requirement was 1944 cuttings for each variety.

3.9 Treatments, Experimental Design and Weeding Periods

Treatments were executed in two sets to represent weed infested periods and weed free periods to the time of harvest (21, 42, 63, 84, 105, 126, 147, 168 days after planting and control) as described in the table of treatments (Table 1).

The experiment was laid out in a randomized complete block design (RCBD) with three replications (Appendix 3). Three varieties (Chila, Mweru and Nalumino) as the main plot treatments and nine weeding periods as subplot treatments. Plots for Weed Free were kept clean all the time up to the time scheduled for weeding.

First control plots ($T9_1$), Weed Free (WF) all time or control, the plots were kept free from weeds all the time up to the harvesting period. Weeding was done by using hand hoe at an interval of 21 days. To control early infestation of weeds, early weeding was done at after 14 days. Second control plots ($T9_2$) WI were kept infested with weeds all the time up to the period of harvest. Weeding regime based on the scheme as described in Table 1.

Table 1: Treatments description set one and two (weed free plots and weed infested plots)

Treatments	Weed free and weed infested periods
(a)	**Set one (1) Weed Free Plots (WF) $T9_1$**
	The plots were kept free from weeds for the first:
T1	21 Days After Planting and then left with weeds (weed infested) until harvest
T2	42 Days After Planting and then left with weeds (weed infested) until harvest
T3	63 Days After Planting and then left with weeds (weed infested) until harvest
T4	84 Days After Planting and then left with weeds (weed infested) until harvest
T5	105 Days After Planting and then left with weeds (weed infested) until harvest
T6	126 Days After Planting and then left with weeds (weed infested) until harvest
T7	147 Days After Planting and then left with weeds (weed infested) until harvest
T8	168 Days After Planting and then left with weeds (weed infested) until harvest
T9	Control Free from weeds all the time (Weed Free) until harvest
(a)	**Set two (2) Weedy plots (WI) $T9_2$**
	Plots were infested with weeds for the first:
T1	21 Days after planting and then weed free up to the harvesting time
T2	42 Days after planting and then weed free up to the harvesting
T3	63 Days after planting and then weed free up to the harvesting time
T4	84 Days after planting and then weed free up to the harvesting time
T5	105 Days after planting and then weed free up to the harvesting time
T6	126 Days after planting and then weed free up to the harvesting time
T7	147 Days after planting and then weed free up to the harvesting time
T8	168 Days after planting) and then weed free up to the harvesting time
T9,	Control (Weedy all) infested with weeds all the time

3.10 Weed Density and Biomass

Before weeding the weed infested plots which were 36 m^2 each, the quadrat measuring 0.5m x 0.5m was thrown three times in each 36 m^2 plot in a zigzag manner at about 3 meters apart. All weeds within each quadrat were manually uprooted, measured the total biomass, identified and counted to determine the number of each species. The samples were dried in an oven at 70 ^{0}C for 48 hours to get dry weight.

3.11 Storage Root Girth and Root Length

The widest part of the root was measured per 36 m^2 using Vernier calliper. Root length was taken from the longest root obtained from 4 plants harvested per 36 m^2 using a rule and metallic tape measure.

3.12 Crop Biomass

Sampling of crop biomass was done at two and three months after planting to observe the trend of plant growth. This involved three plants at 2 months and three plants at 4 months. Three cassava plants were sampled. Then harvesting of crop biomass was done at 6 months after planting, whereby 4 plants were harvested from each plot of 36m^2 (Fig. 3). The determination of crop biomass was done following the procedure described by Fukuda *et al.* (2010). The variables included storage root weight, storage root girth, storage root length, Leaf area and leaf area index (LAI). These are yield components of cassava (Ntawuruhunga, 2001). Final results for conclusion based on the 4 plants which were harvested at six months after planting. Leaves, stems and roots were detached from plants and weighed separately. Leaf samples were dried at 70 ^{o} C for 48 hours and Storage root samples were chopped into small pieces (about 2 cm) to enhance drying at temperature of 100^o C for 36 hours (Ekanayake 1996 and Chikoye *et al*., 2008). The dry

weight was taken to be used to cross check data consistence in terms of weight. The biomass was measured as gram per harvested plant and finally were executed to get tonnes per hectare. The number of live and dead plants for each 36 m^2 was counted. All live plants per 36 m^2 and harvested plants per 36 m^2 were counted and recorded.

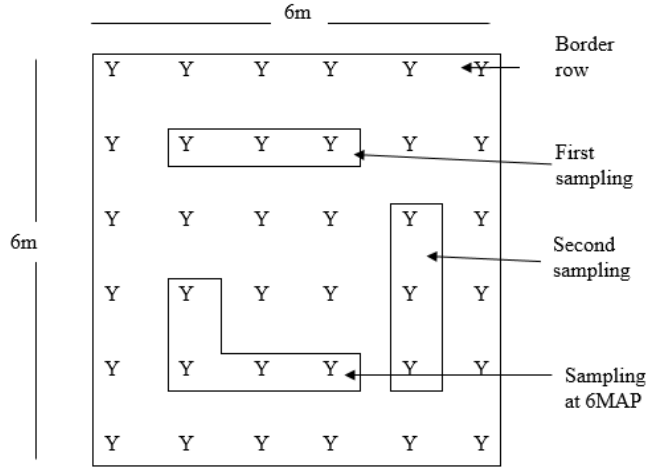

Figure 3: Plants arrangement for sampling

3.13 Leaf Area, Cassava Canopy and Leaf Area Index

Prior to harvest, at six months after planting, the leaf area was taken by using LI-3100 Area Meter. Leaves of cassava were harvested and counted to get total number of leaves per plant. As per Ekanayake (1996), 3 plants were randomly selected per 36 m^2 and 15 leaves within the plant were sub-sampled and measured to get leaf area. The leaf area of the plant was calculated using the procedure described by Ekanayake (1996). During leaf collection, fully open leaves with opened leaflets per plant were considered; these are the leaves which contribute to the photosynthetic activity of the plant. Cassava leaf were placed between the guides on the transparent belts and allowed to pass through the instrument where it was scanned and calculated to get leaf area.

Plant canopy was measured by using a metallic and wooden rule. The rule was placed on top of the plant and measured the width and length of the branching plant (North-south and East-west direction). These were multiplied to get the ground area which was used together with leaf area to get leaf area Index (LAI). LAI is the ratio between leaf area and ground area occupied by the plant

$$Leaf\ Area\ Index = \frac{Leaf\ Are}{Ground\ Area} \quad \text{……..……..(1)}$$

3.14 Root Harvest Index

Root Harvest index (HI) is the proportion of the fresh root weight in biomass. Harvest index was obtained from 4 plants harvested per 36 m^2 and it was calculated by determining the proportion between root weight and the weight of roots plus the plant biomass (weight of roots, leaves and stems). The following formula was used

$$\text{Harvest Index} = \frac{Weight\ of\ roots}{Weight\ of\ roots + Weight\ above\ ground\ biomass}$$

……..(2)

3.15 Data Analysis

Analysis of Variance (ANOVA) basing on statistical model for split plot design was used as: $Y_{ijk} = \mu + \beta_i + A_j + \delta_{ij} + B_k + AB_{ik} + \varepsilon_{ijk}$ (Y_{ijk} = Output, μ = General mean, β_i = block effect, $A \wedge B$ = Factor A and B respectively, δ_{ij} =Error A main plot error and ε_{ijk} = Error (sub-plot) random error effects). GenStat statistical software was used to analyse data. The type of analysis performed was the analysis of variance. Separation of means of the different treatments was done by Tukey's honest significance

test. Data for root yield, leaf area and leaf area index, were transformed by square root transformation.

3.16 Crop Data Sampling Procedures and Data Analysis for Yield Loss

Within the 36 plants grown per 36 m^2, 4 plants from each plot (36 m^2) were harvest at an age of 6 months after planting. One row (guard/border row) of cassava was left from each side of the plot and the harvested cassava storage roots were weighed using the weighing scale to obtained biomass.

Data of storage root weight from weed free plots and weed infested plots were used to estimate yield losses caused by weeds in cassava farms in the two districts. These data were processed by GenStat statistical package. The mean was used to determine crop yield loss. This was determined by calculating and comparing the performance between actual yield obtained from weedy plots and yield obtained from plots with absence of weed. Analysis of Variance (ANOVA) basing on statistical model for split plot design was used as: $Y_{ijk} = \mu + \beta_i + A_j + \delta_{ij} + B_k + AB_{ik} + \varepsilon_{ijk}$, Y_{ijk} = Output, μ = General mean, β_i = block effect, $A \wedge B$ = Factor A and B respectively, δ_{ij} =Error A main plot error and ε_{ijk} = Error (sub-plot) random error effects.

Yield loss was calculated following procedure designed by FAO, 2003 modified by Bisimwa *et al*., 2015 and the following formulas were used.

$$WTL = \frac{UWF - DWI}{UWF} X\ 100 \quad \text{……..}$$

…….(3)

% WTL= Percentage Weight loss, DWI = Weight of roots in field with weeds and

UWF = Weight of roots in Weed free field all the time

CHAPTER FOUR

4.0 RESULTS

4.1 Results

4.1.1 Soils

The soils properties for Kaoma and Chongwe were variable (Table 2) ranging from medium to slightly acidic (pH5.4-5.6). The Organic matter in both sites are very low below the critical value. Phosphorus is low in Kaoma, high in Chongwe. Calcium levels are high in both sites

Table 2: Soil chemical properties variability in weed density trial in Kaoma and Chongwe - Zambia, December 2016

Site	HT	pH $CaCl_2$	Org C %	N %	P Ppm	K ppm	Ca ppm	Mg ppm	Na ppm	CEC me %	(Kg/Ha)
Kaoma	SC	5.4	0.4	0.01	23	55	1620	47	33	6.49	Nil
Chongwe	SL	5.6	0.7	0.03	60	71	2211	262	37	11.41	Nil
Critical Values		4.5	1.58	0.1	15	40	200	50			

Texture Key: S=Sand, LS=Sand Loam, CL=Clay Loam. pH -$CaCl_2$ below 4 Extremely acidic, 4=Strongly acidic, 5=Medium Acidi,7=Neutral

4.1.2 Rainfall

The total amount of rainfall during the trial season from October 2016 to June 2017 at Chongwe experimental site was 906.2 mm and at Kaoma was 1221.9 mm. Both sites (Chongwe and Kaoma) had more rainfall in January than other months (Fig. 4). Both sites, Kaoma and Chongwe, had adequate rainfall for growth of Cassava. Kaoma had more rainfall as compared to Chongwe which had 906.2mm during the growing season.

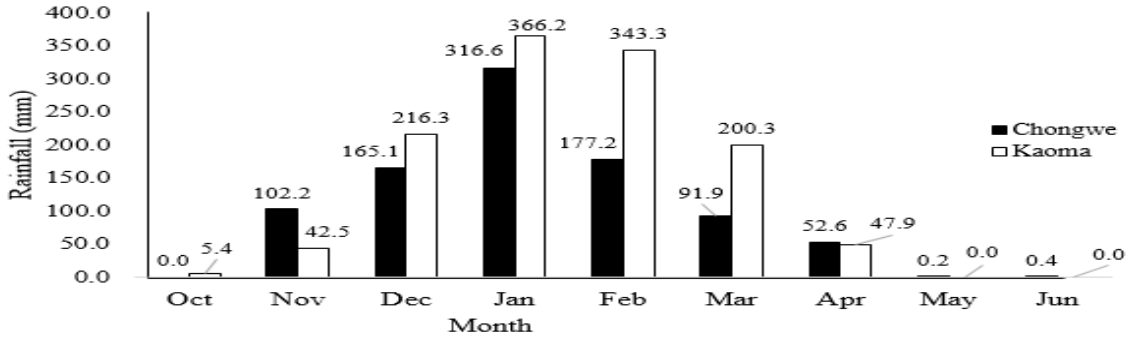

Figure 4: Monthly average rainfall (mm) at Chongwe and Kaoma from November 2016 to June 2017

4.1.3 Temperature

Average temperatures were between 19.7 °C and 27.4°C in Chongwe from October 2016 to May 2017 and in Kaoma temperature records were between 18.7°C and 26.4°C for the same period (Fig. 5 and 6). Maximum Temprature in Chongwe was observed in October the minimu temperature was observed in May. Both site experienced high average temperatures in October and lowest average temperatures in May.

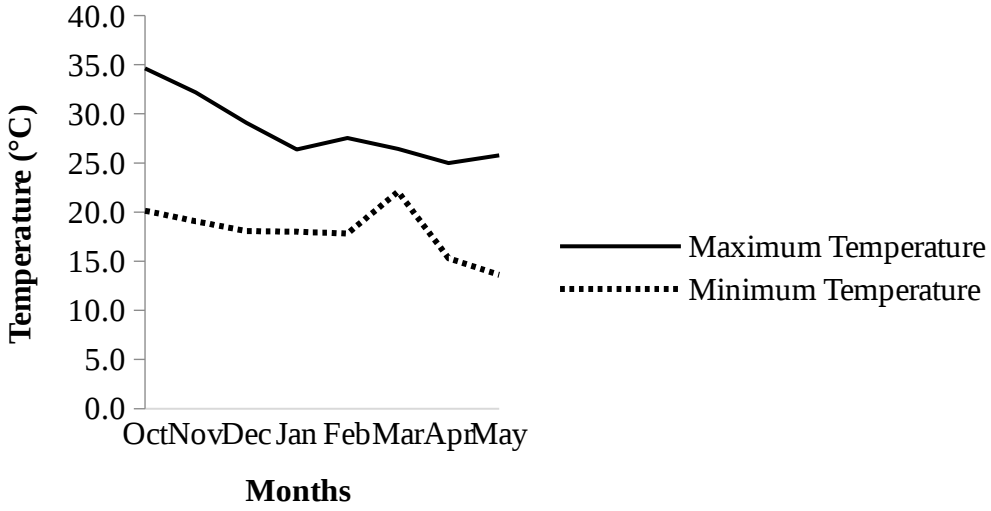

Figure 5: Monthly temperature (^{0}C) at Chongwe season 2016/17

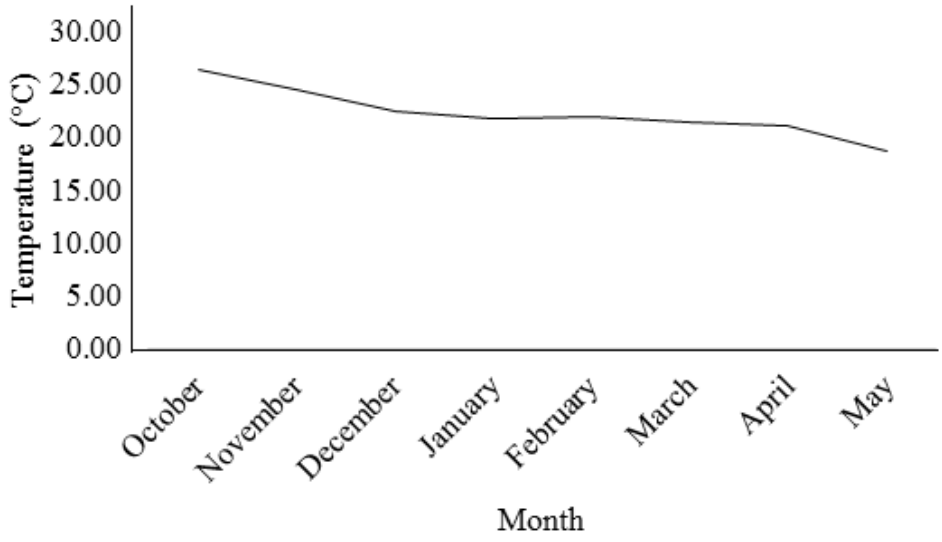

Figure 6: Monthly average temperature (°C) at Kaoma season 2016/17

4.1.4 Farmer survey results

(a) Field history

The highest percentage of the cassava fields surveyed were under continuous cassava production for more than one farming season (Table 3). Only a few number of cassava fields were newly opened fields cropped with cassava.

Table 3: Field history

Field history	Frequency of field history	Percent
Recently cleared	15	18.5
Cultivated for a long time (more than one farming season)	41	50.6
Cultivated with cassava last season	18	22.2
Not cultivated last season	6	7.4
cultivated with maize	1	1.2
Total	**81**	**100**

(b) Weed species

Farms survey results indicated that the most common weeds were *Richardia scabra* and *Bidens schimperi* with the highest percentage (Table 4). Weeds that appear every year in the farmer fields were regarded as most common. Weeds that re-emerge and sprout easily soon after weeding has taken place were regarded as most troublesome. Weed species which were mentioned as most common were *Hyperrhenia spp, Eragrostis spp, Panicum maximum* and *Digitaria milanjiana* (Table 4). Weed species with highest frequency that could not dry easily after weeding were also regarded as most troublesome (for example *Richardia scabra*).

Table 4: Common weeds

Weed species Scientific name	Weed common names	Life cycle	Frequency	Percent
Richardia scabra	Rough Mexican clover	Annual	47	43.5
Bidens schimperi	Munondo bur- marigold	Annual	46	42.59
Cynodon dactylon	Bermuda grass	Perennial	8	7.41
Panicum maximum	Guinea grass	Perennial	2	1.85
Eragrostis spp	Love grass	Perennial	2	1.85
Hyparrhenia spp	Thatching grass	Perennial	2	1.85
Digitaria milanjiana	digit grass	Perennial	1	0.93

(c) Weed management

i. Time to start weeding

The management of weeds done by farmers varies from one farmer to another. They differ in their time of starting to weed, time of stopping, weeding technique and source of labour. Results show that most farmers start weeding cassava field four 4 weeks after planting (Table 5).

Table 5: Frequency and percentage about time when famers start weeding Cassava in Kaoma

Period	Frequency	Percent
After two weeks	6	7.4
After three weeks	10	12.3
After four weeks	19	23.5
After five weeks	11	13.6
After six weeks	10	12.3
After seven weeks	5	6.2
After eight weeks	15	18.5
After nine weeks	1	1.2
after twelve weeks	2	2.5
After sixteen weeks	1	1.2
after 28 weeks	1	1.2
Total	**81**	**100**

ii. Time to stop weeding

Results shows that the largest proportion of interviewed farmers stopped weeding 2 months after planting, 14.8% stops after 7 months and 13.6% stops 8 months after planting (Table 6). The majority stop 6-8 months after planting.

Table 6: Time when famers stop weeding

Time of weeding	Frequency	Percent

One month after planting	8	9.9
Two months after planting	13	16
Three months after planting	6	7.4
Four months after planting	6	7.4
Five months after planting	8	9.9
Six months after planting	10	12.3
Seven months after planting	12	14.8
Eight months after planting	11	13.6
When ready to harvest	3	3.7
Three years	1	1.2
After weeding three times	1	1.2
When crop have grown enough	1	1.2
Total	80	98.8
Missing	1	1.2
Total	**81**	**100**

iii. Weeding technique

The largest proportion of farmers use hand hoe to perform weeding in their cassava fields (Table 7). No other weed management techniques such as use of herbicides were practised by farmers.

Table 7: Weeding technique

Description	Frequency	Percent
Hand hoe	79	97.5

Missing	2	2.5
Total	**81**	**100**

iv. Source of labour for weeding

The source of labour for weeding cassava field were family labour, hired labour and communal. The highest percent and frequency was family labour followed by hired labour (Fig. 7).

Figure 7: Source of labour for weeding

(e) Farmers opinions concerning cassava production

According to the results of famer survey, the greatest proportion of farmers expressed the demand for the use of herbicides to reduce drudgery (Table 8). However, farmers realised that weeding in cassava is important in order to improve cassava production.

Table 8: Opinions of farmers concerning cassava production

Opinion	Frequency	Percent
Herbicides are needed in cassava to reduce workload	30	37.0
Weeding in cassava is important	25	30.9
Government should support training (weeding technique, improved planting materials)	10	12.3
Weeds is the problem and weeding is expensive	7	8.6
Government should support Implements for weeding,	3	3.7
Government should support on Market,	2	2.5
Government should support funds (loans) on weed control	2	2.5
Government should support research on weeding technics and fertilizers	2	2.5
Total	**81**	**100**

(d) Challenges facing farmers in cassava production

Apart from weed problem, farmers are faced with several challenges According to results, the key challenges in addition to weed were fire outbreak, lack of land and rats (Table 9).

Table 9: Challenges which farmer face in cassava production

Challenge	Percent
Fire outbreak	15.96
lack of land	12.01
Rats	12.01
Weather (too much rain)	11.79
Lack of labour	10.57
Animals	10.20
Diseases and insects	10.07

Soil moles	9.18
Lack of improved seed	8.20
Total	**100**

4.1.5 Weed Species Diversity in Cassava Growing Areas of Kaoma and Chongwe districts in Zambia

(a) Kaoma

Results of weeds in Kaoma shows that *Panicum spp* had high abundance than all other species followed by *Pennisetum spp* and *Bidens schimperi* (Table 10). Weeds that had high frequency 70 and above were *Pennisetum spp, Bidens schimperi, Cynodon dactylon, Dactyloctenium aegyptium and Panicum maximum.* Although *Panicum maximum* had high abundance than other weeds, it had lower frequency when compared to *Pennisetum* (Table 10). In the group of broad leaf weed, the weed with high density was *Bidens schimperi.* Dominant species in family Poaceae were *Pennisetum spp* followed by *Cynodon dactylon*, Panicum *maximum* and *Dactyloctenium aegyptium.*

Results show there is similarity of weed species found in Kaoma and weeds found in Chongwe. Example of weed species that were recorded with high abundance in both sites is *Panicum spp* and an example of weed species with low abundance in Kaoma as well as in Chongwe is *Tridax procumbens* (Tables 10 and 13).

Table 10: Weed density and abundance in Kaoma

Weed Species	Common name	∑Dki	MFDk	F_k	U_k	$MIFD_k$	RF_K	RU_K	RD_K	RA_K)
Panicum maximum	Guinea grass	466	46.61	70	48	66.59	5.9	11.3	38.7	55.92
Pennisetum spp	Fountaingrasses	171	17.11	90	49	19.01	7.6	11.6	14.2	33.38
Bidens schimperi	Munondo bur- marigold	24.3	2.43	90	44	2.7	7.6	10.4	2.02	20.02
Blumea spp	Blumea	148	14.82	30	19	4.94	2.5	4.48	12.3	19.32
Dactyloctenium aegyptium	Egyptian crowfoot grass	92.6	9.26	70	21	1.32	5.9	4.95	7.68	18.57
Cynodon dactylon	Bermuda grass	49.9	4.99	80	24	0.62	6.8	5.66	4.14	16.58
Indigofera spp	Indigo plan	42	4.2	60	28	0.7	5.1	6.6	3.48	15.17
Richardia scabra	Rough Mexican clover	24.7	2.47	60	28	4.12	5.1	6.6	2.05	13.74
Fimbristylis exilis	Fimbry	45	4.5	40	19	11.25	3.4	4.48	3.73	11.6
Cyperus esculentus	Nut gras	14.7	1.47	50	17	2.94	4.2	4.01	1.22	9.47
Tragus berteronianus	carrot-seed grass	32.2	3.22	40	14	8.05	3.4	3.3	2.67	9.36
Corchorus olitorius	Jute mallow	15.4	1.54	40	18	0.39	3.4	4.25	1.28	8.91
Crotalaria spp	Rattlepods	5.6	0.56	60	12	0.09	5.1	2.83	0.46	8.38
Striga asiatica	Witchweed	7.3	0.73	50	13	0.15	4.2	3.07	0.61	7.91
Crotalaria spp	Rattlepods	4.1	0.41	40	14	0.1	3.4	3.3	0.34	7.03
Setaria pumila	Yellow foxtail	21	2.1	20	11	1.05	1.7	2.59	1.74	6.03
Borreiria subvulgata	Broadleaf buttoneweed	0.5	0.05	30	3	0.02	2.5	0.71	0.04	3.29
Hibiscus meeusei	Small-flowered kenaf	2.9	0.29	20	5	0.15	1.7	1.18	0.24	3.11
Euphorbia hirta	Asthma plant	1	0.1	20	4	0.05	1.7	0.94	0.08	2.72
Eleusine indica	Crowfootgrass	5.3	0.53	20	2	0.27	1.7	0.47	0.44	2.61
Vernonia petersii	Vernonia	10.3	1.03	10	3	1.03	0.9	0.71	0.85	2.41
Commelina benghalensis	Wandering Jew	0.9	0.09	20	2	0.05	1.7	0.47	0.07	2.24
Hyparrhenia spp	Thatching grass	5	0.5	10	3	5	0.9	0.71	0.41	1.97
Dactyloctenium giganteum	Crowfoot grasses.	2.4	0.24	10	2	0.24	0.9	0.47	0.2	1.52
Cyperus rotundus	Nut sedge	1.7	0.17	10	2	0.17	0.9	0.47	0.14	1.46
Dichrocephalla integrifolia	Veronia	0.3	0.03	10	2	0.03	0.9	0.47	0.02	1.34
Tridax procumbens	Coatbuttons or tridax daisy	0.2	0.02	10	2	0.02	0.9	0.47	0.02	1.34
Cleome monophyla	Spider weeds	2.8	0.28	10	1	0.28	0.9	0.24	0.23	1.32
Nicandra physalodes	Shoo fly	0.4	0.04	10	1	0.04	0.9	0.24	0.03	1.12
Convolvulus sagittatus	Bindweed	0.2	0.02	10	1	0.02	0.9	0.24	0.02	1.1
Leucas martinicensis	whitewort	0.1	0.01	10	1	0.01	0.9	0.24	0.01	1.09
Mariscus sublinus	Mariscus	0.1	0.01	10	1	0.01	0.9	0.24	0.01	1.09
Helichrysum argyrosphaerum	Strawflower	0.1	0.01	10	1	0.01	0.9	0.24	0.01	1.09

Key: sum field density (∑Dk), mean field density (MFD_k), uniformity (U_k), mean infested Field Density ($MIFD_k$), relative frequency (RF_K), relative uniformity (RU_K), frequency (F_k) relative density (RD_K) and relative abundance (RA_K) in Kaoma

In Kaoma the family Poaceae had higher frequencies compared to other families like Leguminaceae, Asteraceae, Cyperaceae, Rubiaceae (Table 11).

Table 11: Percentage of frequency of weed families in Kaoma, Zambia

Family (FN)	Percentage of family frequency
Poaceae/Graminae	44.6
Leguminaceae	14.3
Cyperaceae	9.8
Rubiaceae	8.0
Scrophulariaceae	4.5
Asteraceae	3.6
Tiliaceae	3.6
Compositae	2.7
Commelinaceae	1.8
Euphorbiacea	1.8
Malvaceae	1.8
Capparaceae	0.9
Convovulaceae	0.9
Lamiaceae	0.9
Solanaceae	0.9

Shannon diversity index (H') was 2.12 and Evenness was 0.63. When comparing with other weeds, *Pennisetum* and *Panicum maximum* showed highest Shannon's index value of 0.36 and 0.35 than others respectively (Table 12). The values for evenness ranged between 0 and 1 with 1 being complete evenness.

Table 12: Species Diversity in Kaoma, West Province of Zambia estimated by Shannon- Wiener Index

Name of Species	Sample Value	pi (Sample/sum)	ln (pi)	pi*ln(pi)
Leucas martinicensis	0.01	0.00005	-9.979	-0.0005
Moriscus sublinus	0.01	0.00005	-9.979	-0.0005
Convolvulus sagittatus	0.02	0.0001	-9.286	-0.001
Tridax procumbens	0.02	0.0001	-9.286	-0.001
Dichrocephella integrifolia	0.03	0.0001	-8.881	-0.001
Euphorbia hirta	0.1	0.0005	-7.677	-0.004
Helichrysum argyrosphaerum	0.1	0.0005	-7.677	-0.004
Borreiria subvulgata	0.14	0.001	-7.340	-0.005
Cyperus rotundus	0.17	0.001	-7.146	-0.006
Cleome monophylla	0.28	0.001	-6.647	-0.009
Hibiscus meeusei	0.29	0.001	-6.612	-0.009
Nicandra physalodes	0.4	0.002	-6.291	-0.012
Crotalaria spp	0.41	0.002	-6.266	-0.012
Hyparrhaenia spp	0.5	0.002	-6.067	-0.014
Eleusine indica	0.53	0.002	-6.009	-0.015
Commelina benghalensis	0.81	0.004	-5.585	-0.021
Striga asiatica	0.82	0.004	-5.573	-0.021
Venonia petersii	1.03	0.005	-5.345	-0.026
Crotalaria spp	1.91	0.009	-4.727	-0.042
Cyperus esculentus	2.01	0.009	-4.676	-0.044
Setaria pumila	2.1	0.010	-4.632	-0.045
Dactyloctenium giganteum	2.4	0.011	-4.499	-0.050
Richardia scabra	2.47	0.011	-4.470	-0.051
Bidens schimperi	3.33	0.015	-4.171	-0.064
Fimberistyles exilis	4.5	0.021	-3.870	-0.081
Corchorus Olitorius	4.51	0.021	-3.868	-0.081
Trugus berteronianus	5.29	0.025	-3.708	-0.091
Indigofera spp	5.64	0.026	-3.644	-0.095
Blemea auritia	14.91	0.069	-2.672	-0.185
Dactyloctenium aegyptium	18.26	0.085	-2.470	-0.209
Cynodon dactylon	18.49	0.086	-2.457	-0.211
Panicum maximum	56.06	0.260	-1.348	-0.350
Pennisetum spp	68.23	0.316	-1.151	-0.364
SUM	**215.78**			**-2.121**

Key: SUM=Summation, pi= Number of individuals of species i/total number of samples S = Total number of species or species richness, ln=Natural logarithm, Evenness (E) = H'/lnS, H' = diversity

(b) Chongwe

In Chongwe, weed species which had high relative abundance than others were *Eleusine indica* and *Rottboelia cochinchinensis* (Table. 13). Thirteen weeds had higher abundance above mean. *Richardia scabra* was more uniform compared with other weed species (Table 13).

Table 13: Weed density and abundance in Chongwe

Weed species	Common name	∑Dki	MFDk	Uk	MIFDk	RFK	RUK	RDK	RAK
Eleusine indica	Crowfoot grass	117.6	11.76	0.7	16.8	4.4	4.4	26.25	35.06
Rottboelia cochinchinensis	Itchgrass	63.2	6.32	0.8	7.9	5.03	5.03	14.11	24.17
Panicum miliaceum	Guinea grass	59.6	5.96	0.8	7.45	5.03	5.03	13.3	23.37
Richardia scabra	Rough Mexican clover	43.2	4.32	1	4.32	6.29	6.29	9.64	22.22
Setaria pumila	Yellow foxtail	37	3.7	0.9	4.11	5.66	5.66	8.26	19.58
Hibiscus meeusei	Small flowered kenaf	28.6	2.86	0.8	3.58	5.03	5.03	6.38	16.45
Melinis repens	Natal grass	43.4	4.34	0.5	8.68	3.14	3.14	9.69	15.98
Urochloa mosambicensis	African liverseed grass	31.7	3.17	0.7	4.53	4.4	4.4	7.08	15.88
Elephantorrhiza elephantina	Elephant's root	53.3	5.33	0.3	17.77	1.89	1.89	11.9	15.67
Spilanthes costata	Spilanthes	29.1	2.91	0.7	4.16	4.4	4.4	6.5	15.3
Panicum dichotomiflorum	Fall panicgrass	27.8	2.78	0.5	5.56	3.14	3.14	6.21	12.49
Leucas martinicensis	whitewort	38.3	3.83	0.3	12.77	1.89	1.89	8.55	12.32
Corchorus olitorious	Jute mallow	38.3	3.83	0.3	12.77	1.89	1.89	8.55	12.32
Cyperus difformis	Small-flowered nutsedge	36.3	3.63	0.3	12.1	1.89	1.89	8.1	11.88
Vernonia petersii	Vernonia	41.8	4.18	0.2	20.9	1.26	1.26	9.33	11.85
Echnochloa colona	Jungle rice	30.4	3.04	0.4	7.6	2.52	2.52	6.79	11.82
Aspilia kotschyi	American rope	18	1.8	0.6	3	3.77	3.77	4.02	11.57
Setaria verticillate	Hooked bristlegrass	39.2	3.92	0.2	19.6	1.26	1.26	8.75	11.27
Aceschynomene indica	Jointvetch	10.1	1.01	0.7	1.44	4.4	4.4	2.25	11.06
Bidens schimperi	Munondo bur- marigold	15.7	1.57	0.6	2.62	3.77	3.77	3.5	11.05
Dactyloctenium aegyptium	Egyptian crowfoot grass	8.8	0.88	0.7	1.26	4.4	4.4	1.96	10.77
Setaria megaphylla	Broad-leaved bristle-grass	35.2	3.52	0.2	17.6	1.26	1.26	7.86	10.37
Crotalaria spp	Rattlepods	23.5	2.35	0.4	5.88	2.52	2.52	5.25	10.28
Cleome monophylla	Spider weed	16.5	1.65	0.5	3.3	3.14	3.14	3.68	9.97
Amaranthus spinosus	spiny amaranth	33.3	3.33	0.2	16.65	1.26	1.26	7.43	9.95
Digitaria milanjiana	digit grass	21.4	2.14	0.4	5.35	2.52	2.52	4.78	9.81
Commelina benghalensis	Wandering jew	32.4	3.24	0.2	16.2	1.26	1.26	7.23	9.75
Corchorus tridens	Wild jute	31.2	3.12	0.2	15.6	1.26	1.26	6.96	9.48
Oxalis latifolia	Sorrel	30.2	3.02	0.2	15.1	1.26	1.26	6.74	9.26
Sida cordifolia	Sida	12.9	1.29	0.5	2.58	3.14	3.14	2.88	9.17
Tridax procumbens	Coatbuttons	25.7	2.57	0.2	12.85	1.26	1.26	5.74	8.25
Acalypha fimbriata	Copper leaf	6.1	0.61	0.5	1.22	3.14	3.14	1.36	7.65
Panicum maximum	Guinea grass	5.8	0.58	0.5	1.16	3.14	3.14	1.29	7.58
Oldenlandia lancifolia	Calycose mille graines	22.2	2.22	0.2	11.1	1.26	1.26	4.96	7.47
Galinsoga parviflora	Gallant soldier	19.3	1.93	0.2	9.65	1.26	1.26	4.31	6.82
Solanum incanum	Sodon apple	14.5	1.45	0.2	7.25	1.26	1.26	3.24	5.75
Bidens pilosa	Black jack	14.3	1.43	0.2	7.15	1.26	1.26	3.19	5.71
Ageratum conyzoides	Goat wed	6.6	0.66	0.3	2.2	1.89	1.89	1.47	5.25
Ipomoea eriocarpa	Morning glory	6.3	0.63	0.3	2.1	1.89	1.89	1.41	5.18
Cyperace esculentus	Nut grass	8.2	0.82	0.2	4.1	1.26	1.26	1.83	4.35

Key: sum field density (∑Dk), mean field density (MFDk), uniformity (Uk), mean infested Field Density (MIFDk), relative frequency (RFK), relative uniformity (RUK), relative density (RDK) and relative abundance (RAK).

The family Poaceae had high percentage of weed families frequency compared to other families Asteraceae, Leguminosae, Tiliaceae, and the lowest was Euphorbiaceae. Within Poaceae family, the species which had high percentage was *Eleusine indica.* Weed species were grouped into 14 families which are Amaranthaceae, Asteraceae, Capparidaceae, Commelinaceae, Convolvulaceae, Cyperaceae, Euphorbiaceae, Lamiaceae, Leguminosae, Malvaceae, Poaceae, Rubiaceae, Solanaceae and Tiliaceae (Table 14).

Table 14: Percentage of frequency of weed families in Chongwe, Zambia

Family name	Percentage of family frequency
Poaceae	43.8
Asteraceae	17.0
Leguminosae	8.0
Rubiaceae	5.7
Malvaceae	4.5
Capparidaceae	2.8
Cyperaceae	2.8
Euphorbiaceae	2.8
Malvaceae	2.8
Tiliaceae	2.8
Convolvulaceae	1.7
Lamiaceae	1.7
Amaranthaceae	1.1
Commelinaceae	1.1
Solanaceae	1.1

The weed species diversity as expressed by Shannon diversity index (H') was high, typical values are generally between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than 4 (Kerkhoff, 2010). *Eleusine indica* showed greater Shannon's index value of 0.230 (Table 15).

Table 15: Species Diversity in Chongwe, Zambia estimated by Shannon-Wiener Index

Weed species	Sample Value	pi	ln (pi)	pi*ln(pi)
Panicum maximum	0.58	0.005	-5.313	-0.026
Acalypha Fimbriata	0.61	0.005	-5.262	-0.027
Ipomoea eriocarpa	0.63	0.005	-5.230	-0.028
Ageratum conyzoides	0.66	0.006	-5.184	-0.029
Cyperace esculentus	0.82	0.007	-4.967	-0.035
Dactyloctenium aegyptium	0.88	0.007	-4.896	-0.037
Aceschynomene indica	1.01	0.009	-4.758	-0.041
Sida cordifolia	1.29	0.011	-4.513	-0.049
Bidens pilosa	1.43	0.012	-4.410	-0.054
Solanum incanum	1.45	0.012	-4.397	-0.054
Bidens schimperi	1.57	0.013	-4.317	-0.058
Cleome monophyla	1.65	0.014	-4.267	-0.060
Aspilia kotschyi	1.80	0.015	-4.180	-0.064
Galinsoga parviflora	1.93	0.016	-4.111	-0.067
Digitaria milanjiana	2.14	0.018	-4.007	-0.073
Oldenlandia lancifolia	2.22	0.019	-3.971	-0.075
Crotalaria spp	2.35	0.020	-3.914	-0.078
Tridax procumbens	2.57	0.022	-3.824	-0.084
Panicum dichotomiflorum	2.78	0.024	-3.746	-0.088
Hibiscus meeusei	2.86	0.024	-3.717	-0.090
Spilanthes costata	2.91	0.025	-3.700	-0.091
Oxalis latifolia	3.02	0.026	-3.663	-0.094
Echnochloa colona	3.04	0.026	-3.656	-0.094
Corchorus tridens	3.12	0.027	-3.630	-0.096
Urochloa mosambicensis	3.17	0.027	-3.614	-0.097
Commelina benghalensis	3.24	0.028	-3.593	-0.099
Amaranthus spinosus	3.33	0.028	-3.565	-0.101
Setaria megaphylla	3.52	0.030	-3.510	-0.105
Cyperus difformis	3.63	0.031	-3.479	-0.107
Setaria pumila	3.70	0.031	-3.460	-0.109
Leucas martinicensis	3.83	0.033	-3.425	-0.111
Corchorus olitorious	3.83	0.033	-3.425	-0.111
Setaria verticillate	3.92	0.033	-3.402	-0.113
Venonia petersii	4.18	0.036	-3.338	-0.119
Richardia scabra	4.32	0.037	-3.305	-0.121
Melinis repens	4.34	0.037	-3.300	-0.122
Elephantorrhiza elephantina	5.33	0.045	-3.095	-0.140
Panicum miliaceum	5.96	0.051	-2.983	-0.151
Rottboelia cochinchinensis	6.32	0.054	-2.924	-0.157
Eleusine indica	11.76	0.100	-2.303	-0.230
SUM	**117.70**		**-156.356**	**-3.487**

Key: SUM=Summation, pi= Number of individuals of species i/total number of samples S = Total number of species or species richness, ln=Natural logarithm, Evenness (E)= H'/lnS, H' = diversity,=0.9

(c) Comparison of biomass of weeds between Kaoma and Chongwe

According to t-test results, there was significant difference (P=0.026) in weed biomass between weed biomass in Chongwe and Kaoma; weed biomass for Chongwe was 5.5 tha^{-1} while Kaoma was 3.7 tha^{-1} and the difference of mean was 1.8 (Appendix 5 t-test).

4.1.6 Critical period of weed control

(a) Summary of ANOVA

The determination for the critical period for weed control involved different variables as shown in table of the summary of the ANOVA showing different variables and significant response at the level of main plot treatment, sub plot treatment and interaction (Table 16). There was very high significant difference at P<0.05 in leaf area, weed biomass, weed biomass, root girth root length and harvest index due to period of weed infestation both in weed free and weedy plots.

Table 16: Summary of ANOVA showing different variables and significant response

Treatment	Significance level	Root yield (tha^{-1})		Leaf area (cm^2)		Leaf Area Index		Weed biomass (tha^{-1})		Root girth (mm)		Root length (cm^2)		Harvest Index	
		WF	WI	WF	WI	WF	WI	WF	WI	WF	WI	WF	WI	WF	WI
(a)	P-value	ns	ns	***	ns	ns	ns	ns	ns	ns	ns	***	ns	**	**
(b)	P<0.05	***	***	***	***	ns	ns	***	***	***	***	***	***	***	***
(a x b)	P<0.05	ns	ns	***	***	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Key: (a) = Varieties (Mweru, Nalumino and Chila), (b) = WF/WI (weed free period and weed infested periods), (a x b) = interaction between cassava varieties and periods of weed free and weed infestation, ns=not significant, *=significant, ** =highly significant, *** = very highly significant

(b) Cassava yield of storage roots

The determination of critical period of weed control was based on the yield of cassava storage roots. These storage roots performed differently according to the period during which the crop coexisted with weeds or the period during which the crop was free from weeds. The largest difference in yield was observed between the plots which were kept weed free all the time to the harvesting period and plots which were left with weeds all the time to the time of harvesting. In Chongwe, there was very high significance difference

(0.001) at ($p<0.05$) in storage root weight between different periods of weed infestation and weed free; when the varieties were kept weed free all the time the yield for Chila was 17.8t ha^{-1}, Mweru 15.2 t ha^{-1} and Nalumino was 20.6 t ha^{-1} (Table 17) while when cassava were left with weeds all the time the yield of storage roots after six months was 0.02 t ha^{-1}, 0.04 t ha^{-1} and 0.0 t ha^{-1} for Chila, Mweru and Nalumino respectively (Table 17). Results show that there was significant difference in root weight between varieties; Mweru variety surpassed Chila and Nalumino in weed free plots but there was no significant difference in root yield in weed infested plots, however there was high significant difference (0.001) at $p<0.05$ in the weight of root obtained in different weeding periods. Results showed that there was no significant different in yield due interaction (Table 17 and Fig. 8).

Table 17: Cassava yield of storage roots of three cassava varieties from weed free (WF) and weed infested (WI) six months after planting – Chongwe

Treatment		Root yield from WF (tha^{-1})	Root yield from WI (tha^{-1})
(a) Varieties:	Chila	9.72 a	2.61
	Mweru	10.38 ab	3.61
	Nalumino	9.49 a	3.79
	Mean	9.86	3.34
	CV (%)	3.2	8.4
	P-value	0.049	0.084
(b) WF/WI:	21 DAP	2.34 a	19.26 c
	42DAP	2.21 a	6.02 b
	63 DAP	5.61 ab	2.93 ab
	84 DAP	10.60 bc	1.29 a
	105DAP	11.61 bcd	0.26 a
	126DAP	12.95 cd	0.12 a
	147 DAP	12.34 bcd	0.12 a
	168 DAP	13.25 cd	0.02 a
	CONTROL	17.86 d	0.02 a
	Mean	9.86	3.34
	CV (%)	26.4	43.1
	P<0.05	0.001	0.001
(a x b) Varieties x WF/WI			
Mean		9.86	3.34
CV (%)		26.4	83.9
P<0.05		0.965	0.490

Key: WF=Weed free treatments set, WI =Weed infested treatments set, DAP=Days after planting, CV=Coefficient of variation, CONTROL =weed infested or weed free all the time, Number followed by letters in the same column are not significantly different at $p \leq 0.05$ according to Tukey. Single/separate analysis for each set (WI and WF).

There was no significant difference due to interaction between variety and period of weed infestation and weed free although there was variation in yields (Fig. 8).

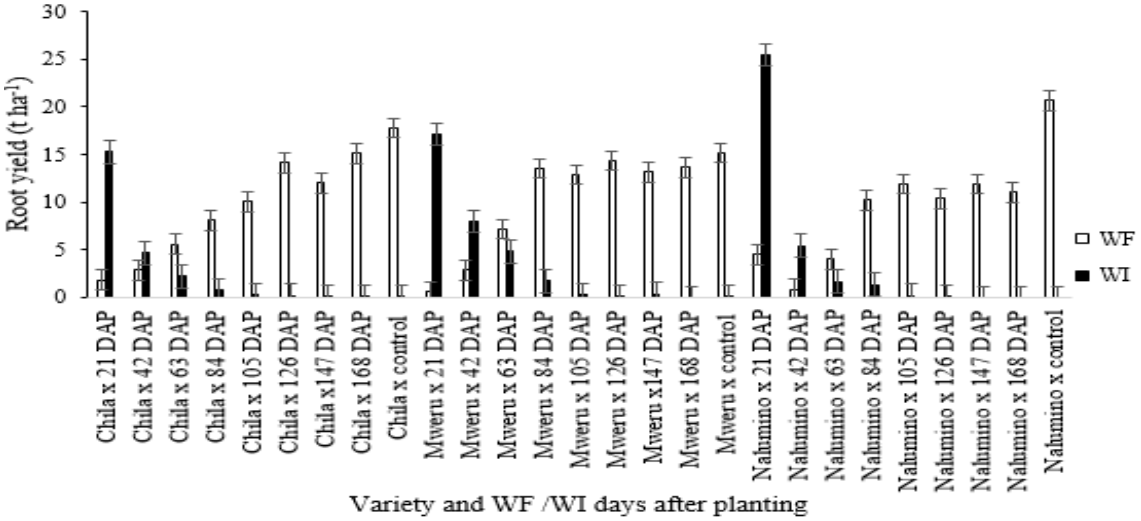

Figure 8: Interaction effect on root girth from weed free (WF) and Weed infested (WI) fields six months after planting in Chongwe

In Chongwe, the critical period for weed removal for Mweru and Nalumino were similar (42-84DAP) and for Chila variety the critical period for weed removal was between 42-105 days after planting as shown in Fig. 9.

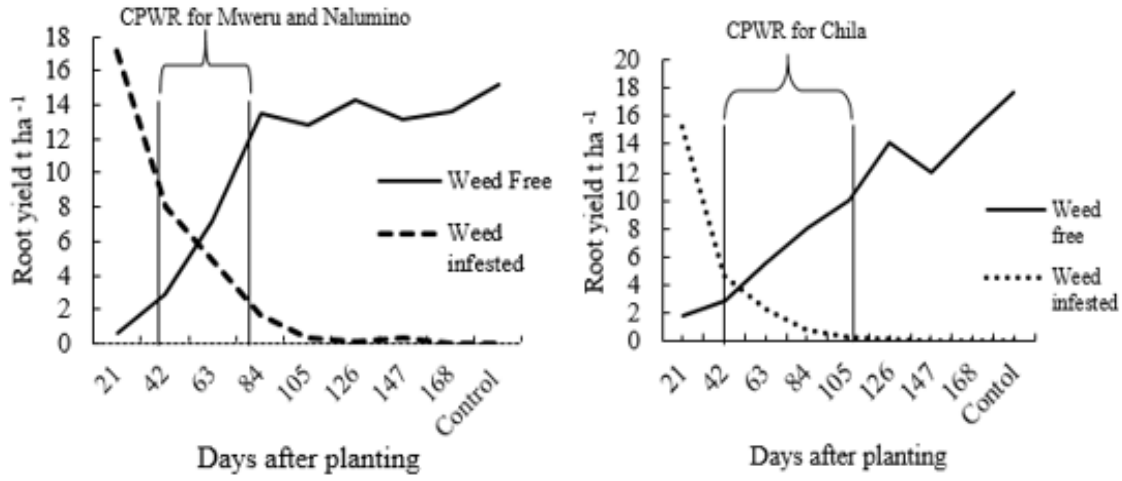

Figure 9: Critical period for weed removal (CPWR) Nalumino, Mweru and Chila in Chongwe

Results for storage root in Kaoma show that there was no significant difference in root yield in weedy plots when the crop coexisted with weeds for 21DAP, 42DAP and 63 DAP (Table 18). There was significant difference in root yield at 84 days after planting. When plots were infested for 126, 147, 168 days after planting and all the time there was no significant difference in root yield (Table 18). However, high yield was obtained when the crop was infested for only 21 days from planting. In the weed free treatments, when it was kept weed free all the time yields were significantly higher than when it was kept weedy all the time. Although there was difference in yield in weed free treatments as well as in weed infested plots due to interaction between varieties and weed free or weed infestation periods, but yields were not significantly different (Table 18).

Table 18: Yield of storage roots of cassava varieties from WF and WI fields 6 months after planting in Kaoma

Treatment		Root yield from WF (tha^{-1})	Root yield from WI (tha^{-1})
(a) Varieties:	Chila	3.75	2.16
	Mweru	2.65	1.52
	Nalumino	3.57	1.85
	Mean	3.32	1.84
	CV (%)	9.6	12.8
	P-value	0.155	0.208
(b)WF/WI:	21 DAP	2.19 ab	5.21 c
	42DAP	1.97 a	3.75c
	63 DAP	2.51 abc	3.61 c
	84 DAP	3.26 abc	1.85 b
	105DAP	3.85 bc	0.58 a
	126DAP	3.83 bc	0.59 a
	147 DAP	4.17 c	0.45 a
	168 DAP	3.89 bc	0.26 a
	CONTROL	4.27 bc	0.29 a
	Mean	3.32	1.84
	CV (%)	19.7	24.8
	P<0.05	0.001	0.001
Interaction effect			
(a x b) Varieties x WF/WI			
	Chila x 21 DAP	2.86	4.29
	Chila x 42 DAP	2.01	5.15
	Chila x 63 DAP	3.08	5.03
	Chila x 84 DAP	3.67	2.69
	Chila x 105 DAP	3.42	0.64
	Chila x 126 DAP	4.89	0.74
	Chila x147 DAP	4.83	0.47
	Chila x 168 DAP	4.06	0.22
	Chila x control	4.95	0.21
	Mweru x 21 DAP	1.70	6.37
	Mweru x 42 DAP	1.86	2.12
	Mweru x 63 DAP	1.46	2.41
	Mweru x 84 DAP	2.06	1.17
	Mweru x 105 DAP	3.41	0.25
	Mweru x 126 DAP	2.81	0.50
	Mweru x147 DAP	3.51	0.42
	Mweru x 168 DAP	3.20	0.21
	Mweru x control	3.88	0.24
	Nalumino x 21 DAP	1.99	4.97
	Nalumino x 42 DAP	2.03	3.99
	Nalumino x 63 DAP	3.00	3.40
	Nalumino x 84 DAP	4.04	1.68
	Nalumino x 105 DAP	4.72	0.85
	Nalumino x 126 DAP	3.78	0.54
	Nalumino x 147 DAP	4.16	0.45
	Nalumino x 168 DAP	4.41	0.36
	Nalumino x control	3.99	0.42
	Mean	3.32	1.84
	CV (%)	19.7	24.8
	P<0.05	0.948	0.132

Key: WF=Weed free treatments set, WI =Weed infested treatments set, DAP=Days after planting, CV=Coefficient of variation, CONTROL =weed infested or weed free all the time, Number followed

by letters in the same column are not significantly different at p ≤ 0.05 according to Tukey. Single/separate analysis for each set (WI and WF).

The Critical period for weed removal for three varieties in Kaoma was 42 -84 days after planting (Mweru and Nalumino) and the critical period for weed removal for Chila in Kaoma was from 63 -105 days after planting as shown in the table (Table 19).

Table 19: Critical period for weed removal (CPWR) in Kaoma

Variety	Critical period for weed removal
Mweru	42-84 Days after planting
Chila	63-105 Days after planting
Nalumino	42-84 Days after planting

Similar to Mweru variety, Nalumino variety in Kaoma demonstrated its critical period for weed removal to be between 42 and 84 days after planting and the graph for critical period for weed removal in Kaoma had similar characteristics with the results in Chongwe. The range for critical period for weed removal for all variety in both sites (Kaoma and Chongwe) was 42 -105 days after planting (Fig.10), this figure shows the range for both sites (Chongwe and Kaoma) and the CPWR was estimated using actual values.

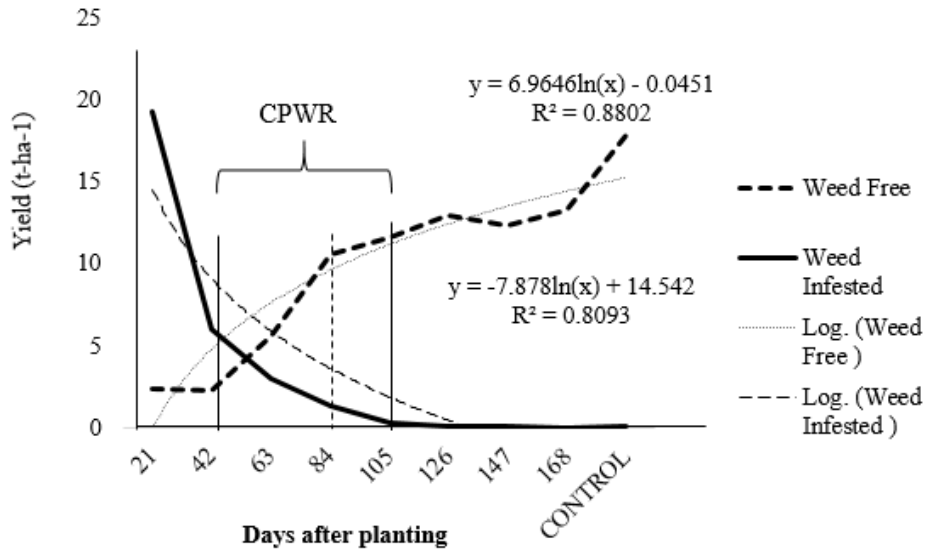

Figure 10: Critical period for weed removal for Chongwe and Kaoma six months after planting for Nalumino, Mweru and Chila

(c)Leaf area and (LA) leaf area index (LAI)

The leaf area per plant was increasing in relation to reduced period of coexistence between cassava and weeds. The largest leaf area was observed when the crop was left with weeds for 21 days after planting (Table 20). In weed free treatments the leaf area was above the mean when the plots were cleaned for 84 days after planting. There was no significant difference in leaf area due to interaction between varieties and periods of weed free and weed infestation. The result for leaf area index in weed free plots showed no significant different between varieties at $p<0.05$ but Mweru had large leaf area index above the mean while other varieties Nalumino was below the mean and Chila in weed infested plots. There was no significant difference in LAI due to different weed free and weed infestation periods. The LAI index in weed free plots was smaller than LAI in weed infested plots (Table 20).

Table 20: Leaf areas and leaf area index from weed free and weed infested plots six months after planting

Treatment	LA cm² WF	LA cm² WI	LAI WF	LAI WI
(a) Varieties: Chila	5071.1 a	4627.7	0.49	0.76
Mweru	4489.6 a	5064.4	0.40	0.84
Nalumino	9798.6 b	5731.9	0.71	0.77
Mean	6453.1	5141.3	0.53	0.79
CV (%)	2.3	20.1	16.0	9.2
P-value	0.001	0.905	0.060	0.486
(b) WF/WI: 21 DAP	2065a	13964 c	0.53	0.73
42 DAP	1600 a	10214 bc	0.42	1.06
63 DAP	2817 a	7550 abc	0.42	0.92
84 DAP	7443 b	5737 ab	0.55	1.00
105 DAP	7192 b	2989 a	0.49	0.88
126 DAP	7798 b	1636 a	0.55	0.85
147 DAP	9005 b	755 a	0.60	0.51
168 DAP	9549 b	2297 a	0.56	0.60
CONTROL	10609 b	1130 a	0.69	0.55
Mean	6453.1	5141.3	0.53	0.79
CV (%)	23.4	42.5	51.8	41.9
P-value	0.001	0.001	0.622	0.338

Key: WF=Weed free treatments set, WI=Weed infested treatments set, LA=Leaf area, LAI=Leaf area index, DAP=Days after planting, CV=Coefficient of variation, CONTROL= weed infested or weed free all the time. Number followed by letters in the same column are not significantly different at $p \leq 0.05$ according to Tukey. Single/separate analysis for each set (WI and WF).

In weed free plots the leaf area was increasing due to number of weed free days (Fig. 11).

The largest leaf area was obtained when the crops was kept weed free all the time

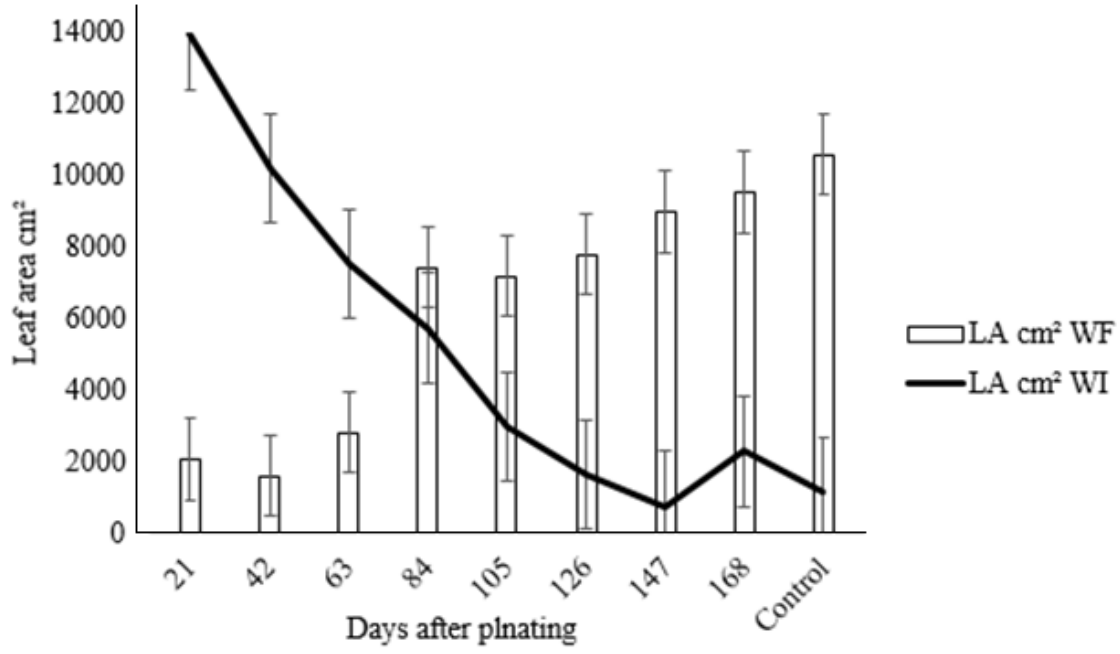

Figure 11: Leaf area (LA) for cassava 6months after planting in weed free (WF) and weed infested plots (WI)

(d)Weed biomass

The lowest weed biomass was observed in plots infested with weeds only 21 days (Table 21). There was a very high significant difference (0.001) at $p<0.05$ in weed biomass between weed free period and weed infested period. Mweru had higher weed biomass than other varieties at 63 days after planting (Fig.12).

Table 21: Weed biomass from weed free and weed infested plots six months after planting

Treatment		Weed biomass in from WF (tha^{-1})	Weed biomass in from WI (tha^{-1})
(a) Varieties:	Chila	6.1	21.8
	Mweru	4.8	27.1
	Nalumino	5.6	22.5
	Mean	5.5	23.8
	CV (%)	3.0	22.8
	P<0.05	0.379	0.501
(b) WF/WI:	21 DAP	12.950 c	6.98 a
	42DAP	14.646 c	29.15 c
	63 DAP	12.067 c	34.45 c
	84 DAP	6.979 b	32.60 c
	105 DAP	2.135 a	26.68 bc
	126 DAP	0.796 a	27.40 bc
	147 DAP	0.000 a	28.36 c
	168 DAP	0.000 a	15.67 ab
	CONTROL	0.000 a	12.97 a
	Mean	5.51	23.81
	CV (%)	17.8	34.1
	P<0.05	0.001	0.001
(a x b) Varieties x WF/WI			
Mean		5.51	23.81
CV (%)		17.8	34.1
P<0.05		0.655	0.497

Key: WF=Weed free treatments set, WI =Weed infested treatments set, DAP=Days after planting, CV=Coefficient of variation, CONTROL =weed infested or weed free all the time, Number followed by letters in the same column are not significantly different at p ≤ 0.05 according to Tukey. Single/separate analysis for each set (WI and WF).

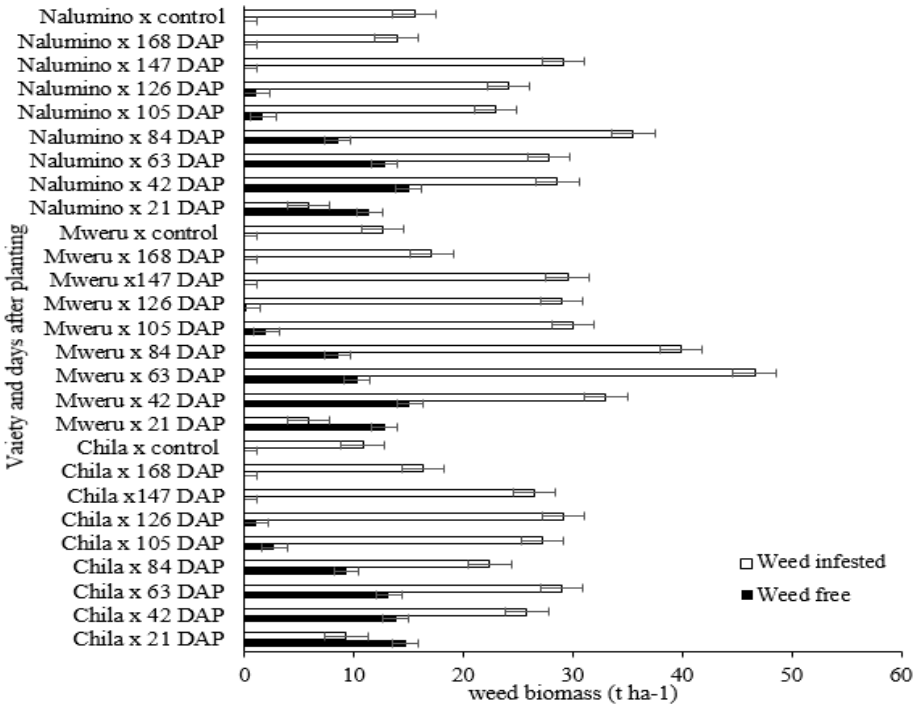

Figure 12: Weed biomass from weed free and weed infested plots six months after planting

Relationship between root yield and weed biomass

The observed relationship between weed biomass and root weight in weed infested was moderate negative relationship (-0.5) under the observed relationship with 95% confidence limits. In weed infested plots, the yield decreased with increase in weed biomass (Fig.13).

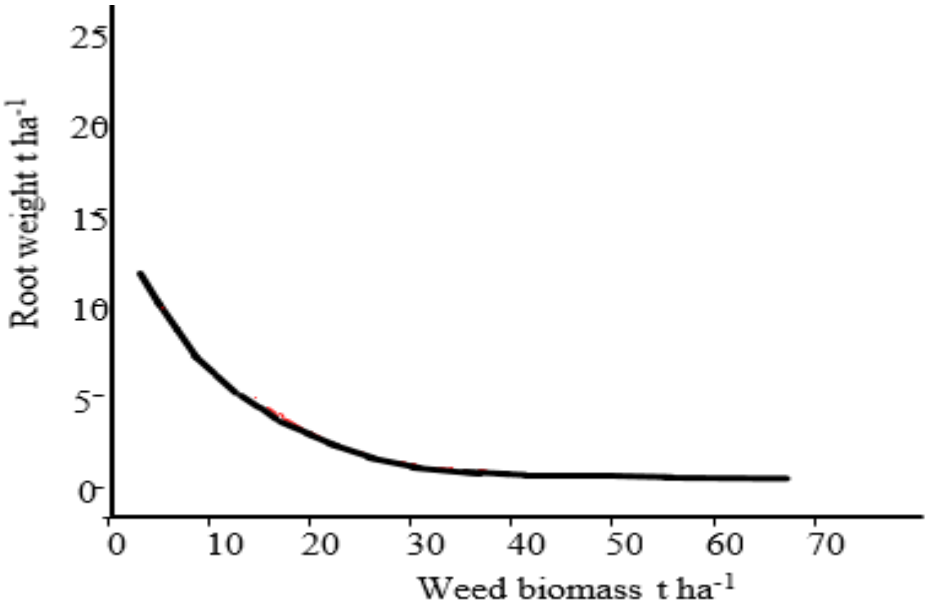

Figure 13: Relationship between weed biomass and root weight in infested treatments

(e) Root girth and root length

There was no significant difference in root girth between varieties at $p<0.05$ but there was significant difference in root girth due to time of weed infestation and time of weed free. There was high significant difference in root girth in weed free treatment but in weed infested it was low at $p<0.05$ (Table 22). The root girth and root length in treatments which were weed free were significantly greater than in weed infested. The was no

significant difference due interaction between varieties and weed free or weed infestation period (Table 22 and Fig.14).

Table 22: Root girth and root length of three cassava varieties from WF and WI fields 6 months after planting in Chongwe

Treatment		Root girth (mm) from WF	Root girth (mm) from WI	Root length ($cm^{2)}$ from WF	Root length (cm^{2}) from WI
Varieties(a)	Chila	34.31	17.9	41.3 b	22.7
	Mweru	31.58	19.6	37.9 a	22.7
	Nalumino	27.07	13.4	47.4 c	23.4
	Mean	30.99	16.96	42.2	23.0
	CV (%)	8.6	16.1	2.6	22.1
	P-value	0.068	0.105	0.001	0.985
WF/WI (b)	21 DAP	18.4 a	39.9 d	23.9 a	54.9 e
	42DAP	24.2 ab	32.6 cd	29.8 ab	45.2 de
	63 DAP	27.2 abc	26.1 c	33.8 ac	34.9 d
	84 DAP	34.6 bc	21.7 bc	43.8 bcd	32.0 cd
	105DAP	34.4bc	11.5 ab	49.3 cd	17.9 bc
	126DAP	33.0 bc	7.3 a	49.9 d	9.1 ab
	147 DAP	35.0 c	5.2 a	49.1 cd	5.8 ab
	168 DAP	35.8 c	4.9 a	48.7 cd	3.7 ab
	CONTROL	36.4 c	3.4 a	51.3 d	3.1 a
	Mean	30.99	16.96	42.2	22.1
	CV (%)	21.7	43.7	24.5	40.9
	P<0.05	0.001	0.001	0.001	0.001

Key: WF=Weed free treatments set, WI =Weed infested treatments set, DAP=Days after planting, CV=Coefficient of variation, CONTROL =weed infested or weed free all the time, Number followed by letters in the same column are not significantly different at p ≤ 0.05 according to Tukey. Single/separate analysis for each set (WI and WF).

There was no significant difference in root girth and root length due to interaction (Fig. 13)

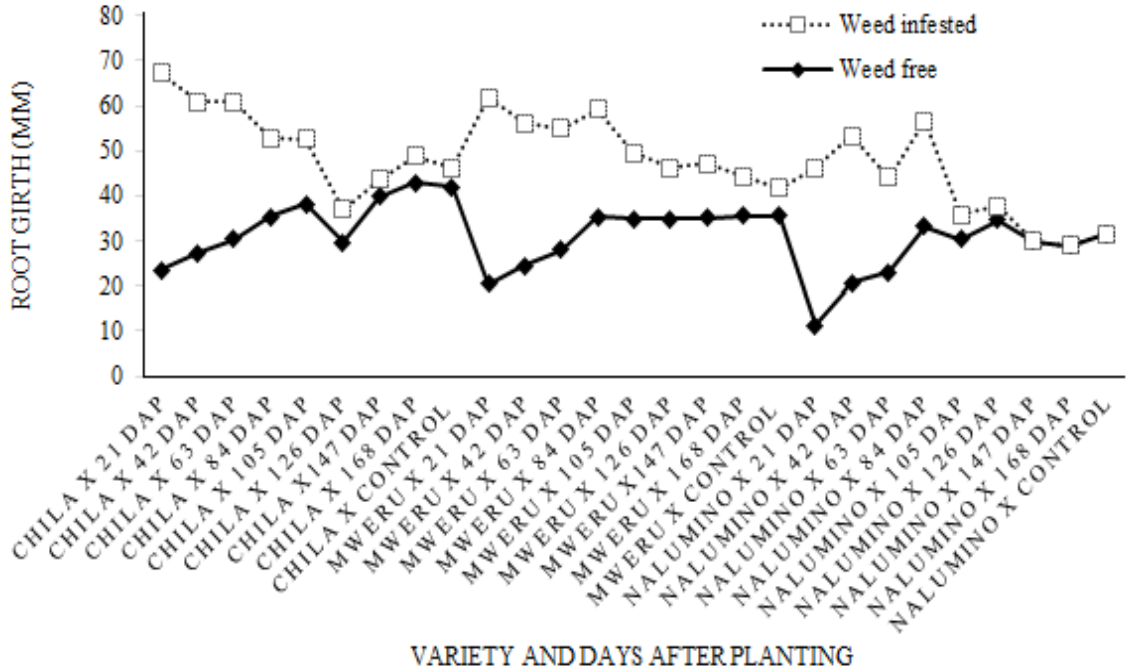

Figure 14: Interaction effect on root girth from WF and WI fields 6 months after planting in Chongwe

4.1.7 Yield Loss Caused by Weeds in Cassava Farms in Chongwe and Kaoma in Zambia

(a) Root yield

According to results from weed free plots, the high percentage of root weight loss above the mean 45 occurred when weeding was done for only 21, 42 and 63 days after planting (Fig.15).

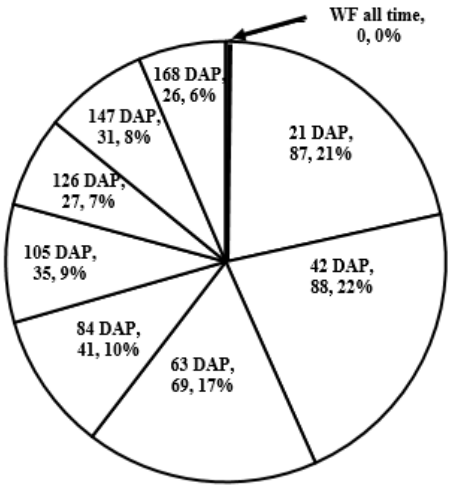

Figure 15: Percentage of Storage root loss in Weed free plots. DAP =Days after planting, WF All=Weed free all the time

High yield losses were recorded when plots were kept weed free for short period of 21, 42 and 63 days after planting (Table 23).

Table 23: Yield loss of storage roots of cassava from weed free and weed infested treatments harvested six months after planting

Days after planting	Storage root loss in weed free treatment t ha^{-1}	Storage root loss in weed infested treatment tha^{-1}
21 DAP	15.5	0.4
42 DAP	15.7	1.6
63 DAP	12.3	5.3
84 DAP	7.3	10.5
105 DAP	6.3	11.6
126 DAP	4.9	12.9
147 DAP	5.5	12.3
168 DAP	4.6	13.3
WF/WI All	0	17.9
Mean	**8**	**9.5**

In weed, infested treatments the loss was 99.99% when weeding was not done all the time. The losses were increasing in relation to the duration of coexistence between the crop and weeds (Fig.16).

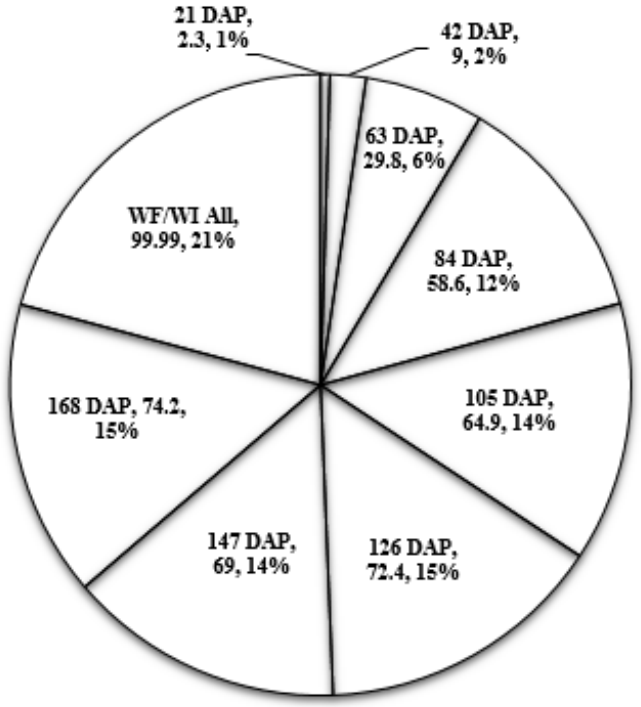

Figure 16: Percentage of Storage root loss in Weed infested plots (WI) D=Days after planting, WI All =Weed infested all the time

(b) Harvest index (HI)

Harvest index is the proportion of the fresh root weight in total plant biomass. It represents genotype yield potential under monoculture (Fukuda *et al.,* 2010). Results show that the proportion of root weight increased when the plant was kept free from weeds. There was very high significance different in HI at $P<0.05$ due to weeding periods; Results show that the greatest harvest index was obtained when plants were kept weed free all the time and when were infested for 21 days only (Table 24).

Table 24: Harvest Index WF and WI of cassava after six months

Treatment		Harvest Index WF	Harvest Index WI
(a) Varieties:	Chila	0.47 b	0.18 ab
	Mweru	0.49 b	0.23 b
	Nalumino	0.41 a	0.14 a
	Mean	0.46	0.18
	CV (%)	3.9	10.6
	P- value	0.017	0.014
(b)WF/WI:	21 DAP	0.18 a	0.53 d
	42 DAP	0.24 a	0.47 d
	63 DAP	0.42 b	0.29 c
	84 DAP	0.51 bc	0.18 b
	105DAP	0.54 bc	0.07 ab
	126DAP	0.51 bc	0.03 a
	147 DAP	0.55 bc	0.06 a
	168 DAP	0.55 bc	0.01 a
	CONTROL	0.62 c	0.01 a
	Mean	0.46	0.18
	CV (%)	21.2	41.4
	P<0.05	0.001	0.001
(a x b) Varieties x WF/WI			
	Mean		0.18
	CV (%)		
	P<0.05	0.660	0.294

Key: WF=Weed free treatments set, WI =Weed infested treatments set, DAP=Days after planting, CV=Coefficient of variation, CONTROL =weed infested or weed free all the time, Number followed by letters in the same column are not significantly different at $p \leq 0.05$ according to Tukey. Single/separate analysis for each set (WI and WF).

The highest Harvest index was recorded in in the plots which were kept weed free all the time in weed free plots. In weed infested plots the highest harvest index was recorded when the crop coexisted with weeds for only 21 days after planting (Fig. 17). There was no significant difference in harvest index due to interaction.

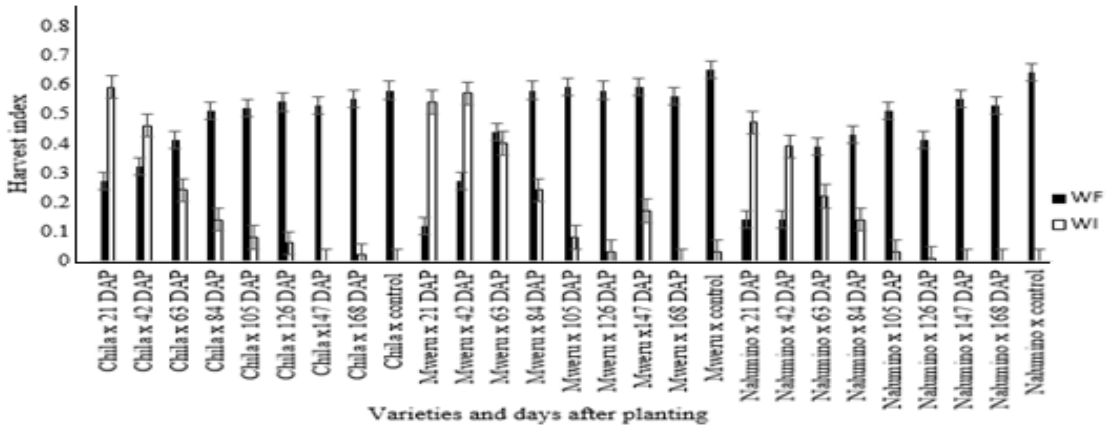

Figure 17: Harvest index of three cassava varieties from weed free and weed infested plots six after planting months

CHAPTER FIVE

4.0 DISCUSSION

4.1 Weed Species Diversity in Cassava Growing Areas of Chongwe and Kaoma Districts in Zambia

The purpose of this study was to estimate weed density, species diversity and their effects on cassava yield in cassava growing areas of Chongwe and Kaoma Districts in Zambia. These investigations intended to answer three fundamental questions which are: What are the weeds species found in cassava growing areas in Chongwe and Kaoma districts in Zambia? What is the critical period for weed removal in the cassava varieties grown in Kaoma and Chongwe and what are the yield losses caused by weeds in cassava.

At Chongwe, 40 weed species were identified and 13 weed species had high abundance. Weeds with high abundance includes *Eleusine indica*, *Rottboelia cochinchinensis, Panicum miliaceum, Richardia scabra*, *Setaria pumila. Hibiscus meeusei*, *Melinis repens, Urochloa mosambicensis, Elephantorrhiza elephantina, Spilanthes costata, Panicum dichotomiflorum, Leucas martinicensis* and *Corchorus olitorious.* Weeds such as *Eleusine indica* had high diversity index (Table 15).

The high abundance of these weeds is the result of their high density and frequency which reflect that they are more dominant. The reasons for the high abundance could be due to their ability to thrive under that environment thus being more competitive than others. The abundance of these weeds could also be due to the favourable environmental. Weeds as plants seem be favoured by soil, temperatures and rainfall.

The pH is ideal for arable farming and good for cassava production (pH 5.5 - 6.5). Organic matter in both sites need more attention and therefore good management such as

conservation tillage are the best ways of enriching soils with Organic carbon which act as a store house for most nutrients. Phosphorous affect the establishment of rooting system, the reason for it being low in Kaoma and Chongwe could be due to high Calcium levels which may be responsible for binding up available phosphates. It is thus advisable not to mix Fertiliser with lime at planting. Lime should be applied before the rains and allowed to react with the soils before basal dress application. The amount of rainfall during the growing season supported weed development. The environmental condition, soil pH and temperatures (25 to 29°C) and rainfall were ideal for growth of cassava as well as weeds.

In Kaoma 33 weed species were identified. Most of the weeds which had high density, frequency and abundance were Poaceae family except *Bidens schimperi* which is Asteraceae. This suggest that the dominant family of weeds species in Kaoma farmers' fields was Poaceae therefore control measures should highly consider such weeds. Poaceae family had high percentage of frequency compared to other weed families like Asteraceae, Leguminosae (Table 11). Results reveal that *Pennisetum* and *Panicum maximum* are more diverse across many fields as compared to other weed flora. Similar weeding recommendation can be suggested for Kaoma and Chongwe because the types of weed species observed in Kaoma do not significantly differ from those found in Chongwe.

Planning for control of weeds must consider factors such as types and characteristics of weeds species emerging during the weeding process. Planning should prioritize abundant weeds. In this case the weeds with high frequency and density such as *Panicum maximum, Richardia scabra, Bidens schimperi, Eleusine indica, Rottboelia cochinchinensis, Setaria pumila, Panicum miliaceum* and *Cyperus spp* be given priority.

The presence of weeds species such as *Bidens spp* and *commellina spp* concur with the results of the report by Silva *et al.* (2013) who reported that *Bidens pilosa* and *Commelina benghalensis* were among the major weeds in areas where cassava is grown. Additionally, (Albuquerque *et al*., 2008) reported that weed species like *Bidens pilosa*, Cyperus *rotundus* and *Commelina benghalensis*, are the prevailing weeds in cassava fields.

These results obtained from farmer survey agreed with results obtained after analysing weed data collected from farmer fields. Weeds species that were mentioned by farmers as most common showed high abundance above the mean (Table 4). Many weed species had high abundance above the mean, examples: *Panicum maximum*, *Pennisetum spp*, *Bidens schimperi*, *Blemea auritia*, *Dactyloctenium aegyptium*, *Cynodon dactylon*, *Indigofera spp*, *Richardia scabra*, *Fimberistyles exilis*, *Cyperus esculentus*, *Trugus berteronianus* and *Corchorus olitorius*. The presence of different weed species confirms the report by IITA, (2000) which state that weed species commonly found in cassava field are put into three main groups (grasses, broad leaf and sedge). Therefore, when planning for weed management in cassava attention should be paid to all three groups of weeds.

The reason for some weed to become more abundant could be due to their ability to produce more seeds than crops, possess period of dormancy which help them survive in adverse condition, deep root system which enable them get nutrients from the soil and small leaf area which minimize losses of water through evapotranspiration. A good example is high the abundance Eleusine *indica* in Chongwe, this might due to the its rooting system which is very well developed and strong. Additionally, results on field history revealed that farmers utilized the same land continuously year after year. Continuous use of the land may lead to depletion of soil fertility henceforth less performance of crops. Depleted soils give room for weeds to grow and becoming more

abundant due their competitive ability. Also, the abundance and availability of seeds in the field could be due to soil seed bank, seed rain, ant-borne seeds and seeds in the vegetation as reported by Buisson *et al.* (2006). The use of hand hoe in weeding, causes repositioning of weed seeds such that some weeds are exposed soil surface which is conducive environment for weed germination, emergence and growth due to presence of fertile soils and exposure to light. This might contribute to the high density of weed seeds as reflected by high weed density observed in farmers' fields.

Some weeds such *Richardia scabra* and *Bidens schimperi*, as were frequently seen in farmer fields were thus making them most common. Frequency describes the percentage of fields visited that contained *Richardia schimperi* and *Bidens schimperi*. Common weeds are frequently seen in the field and troublesome are most difficult to manage although also may not be wide spread. Apart from the weed species which were mentioned, there were more common weeds species in farmers field, therefore when planning for weed management, attention on availability of different weed species should be considered. These results from field observation regarding types of weed species agree with the results from farmer survey therefore, considering common weeds when planning for weed management can bring a vibrant effect.

Richardia scabra showed high uniformity than other weeds in Chongwe. Uniformity measures how even it is across the fields, and weeds such as *Cyperus esculentus* and *Oxalis latifolia* had low uniformity, this reveal that they are only found in patches.

Additionally, there was a significant difference at $P<0.05$ in weed biomass from weed free plot between Chongwe and Kaoma. More weed biomass were recorded in Chongwe than Kaoma. The reason could be due to high diversity observed in Chongwe than in Kaoma.

Also in Kaoma the experiment was dominated by Cyperaceae while in Chongwe the experiment was dominated by Poaceae. The weed species in Poaceae were more vigorous than weed species in Cyperaceae and there contributed to less biomass in Kaoma.

4.2 Critical Period for Weed Control in Cassava Varieties Commonly Grown in the Chongwe and Kaoma

Basing on the average yield of storage roots, all varieties produced yield above the mean when kept in weed free condition compared to weed infested condition where the yield was below the mean. In weed free condition, Mweru variety produced more yield compared to Nalumino and Chila. When varieties were kept in weedy condition, Chila variety was more affected than others because it produced below the mean. This suggests that Chila is more sensitive to weed infestation and Mweru is more competitive to weeds than other varieties.

The yield above the mean for weedy plots was obtained when the crops were weed infested for 21days and 42 days only but when it was weed free, the production above the mean was obtained 84 days after planting onward (Table 17). Therefore, basing on these yield difference, the following are the critical period for weed removal for the varieties in respect to locations and variety: in Chongwe, the CPWR was 42-84 days after planting (Mweru), 42-105 days after planting (Chila), 42-84 days after planting (Nalumino) and for Kaoma were 42-84 days after planting (Mweru), 63-105 days after planting Chila and 42-84 days after planting (Nalumino).

These findings reveal that critical period for weed removal when cassava crop is harvested six months after planting was between the second and the third month after planting (42 and 105 days after planting). Therefore, in average the critical period for weed control for

all varieties was between 1.5 month to 3 months, meaning that, to get good yields, it is therefore necessary to keep the field weed free for first 1.5 -3 months.

To maximize production in cassava, weeding should be maintained for at least four months from planting. This is the period when canopy development take place. However due to limitation of labour, weeding must be done between the second and third month after planting. In the assessment of critical period of weed competition in cassava fields, A'ihi *et al.* (2017), reported different critical periods from different countries by citing different authors; according to the paper about the review of critical period of weed completion in cassava fields, the following critical periods, days after planting (DAP) were reported; 20-60 in Cameroon (Ambe *et al.*,1992), 28-70 in Brazil (Albuquerque, 2008), 35-84 in Ibadan Nigeria (IITA, 1992), 40-84 in SE Nigeria (Akobundu, 1980), 42-84 in Umudike Nigeria (Melifonwu, 1994), 66-911 in Canada (Costa *et al.*, 2012). In view of these reports, the results concur with other above-mentioned scientists and are giving similar paradigm despite of minor difference in the approach but basing on the sites and varieties used these findings are new.

The yield of cassava roots was decreasing according to the time of weed infestation (Fig.13) indicating that the more the time of crop coexistence with weeds the greater the yield reduction. In connection to this the increase in weed biomass could be due to increase in weed size and increase in number seedlings emerging as time elapsed; the emerging seedlings could be due to characteristics of weeds regaining their viability and overcoming their state of dormancy as reported by Adesina *et al.* (2012) which in this case it supports the findings of this research.

According to results, farmers do not consider control of early emerging weeds because 23% of farmers start weeding four months after planting. Also, 16% of farmers stop

weeding two months after planting. This may affect yield because two months after planting is the time when the cassava canopy has not developed. Therefore to maximize production, weed management should be prolonged for not less than 105 days after planting instead of two months which is current farmers practice.

The common used equipment for weed management by smallholder cassava production is the hand hoe; but this technique is a challenge, and it limits cultivation of big farms. Low production is also associated with cultivation of small fields which is the result of using hand hoe because farmers cannot manage big farms using hand hoe. Conversely, the major source of labour for cassava weed management is family, it means if the change of technology is done at family level, the whole community will certainly acquire the knowledge and drastic change can easily be achieved through family. During farmer survey, results disclosed challenges linked with cassava production like fire outbreak, rodents, disease control and lack of improved seeds, therefore, investment in solving challenges would scale up cassava production. Furthermore farmers suggested the use of herbicides to manage weeds because hand hoe is drudgery and time consuming.

The increase and decrease in leaf area showed similar trend with the increase and decrease of root yield. These variables such as leaf area, harvest index increased in relation to decrease in weed infestation and they decreased when weed infestation period increased. An additional variable that obeyed the rule used for determination of CPWR was harvest index (HI). By following the results of harvest index, the general critical period for weed removal in Kaoma was 42-84 days after planting. The greatest harvest index was obtained in plots which were kept weed free all the time, and it was highly significant different from other weed free period. Also, the harvest index in weed infested plot was large compared to other when the crop was infested for only 21 days after planting. When it

was infested all the time the HI was small. This imply that the presence of weeds in the field affect crop variables.

4.3 Yield Losses Caused by Weeds in Cassava Farms

Yield losses in Cassava increased with the duration of weed infestation, losses were from 0 to 87% for weed free plots and from 2.32 to 99.99% for weed infested plots. This imply that the longer the period the crop remains with weeds the more the competition, therefore famers should not allow the crop to remain with weeds in the field for long period of time. These results are similar to results reported by Khanthavong *et al.* (2016). The losses of yield could be due to less light exposure, which impair crop biomass (stem, leaves and the roots) by shading which result to poor growth of cassava both the plant and storage roots as reported by Soares *et al.* (2016). Also weeds appearing for the first 84 days after planting reduced storage root yield by 58.6% in weed free set (Fig. 15), therefore early weeding for the first 3 months is important because it saves more than half of the expected yield.

The weed biomass in weed free plots when the crop was weeded for only 21 days after planting was 12.95 th^{-1} and the storage root yield loss was 15.5 t ha^{-1}, this signify that 1 tonne of fresh biomass caused a loss of 1.2 tonne of storage root fresh weight. This concur with the report by Hasanuzzaman (2015). When the crop was left with weeds all the time, the weed biomass produced was 12.97 and the yield loss was 17.9 t ha^{-1}, which is equal to a loss of 1.4 tonnes of storage root fresh weight due to 1 tonne of fresh weed biomass per hectare. These results reveal that, the yield loss is associated with biomass, the more the biomass is accumulated in the field the higher the losses are invited.

The harvest index decreased with duration of weed infestation. Moreover, the increase in weed biomass lead to decrease in the harvest index. The effects of weeds leading to

decrease in harvest index resulted to low yield with a 99.99% yield loss. The effect of yield loss might be associated directly and indirectly with effects on Harvest index and leaf area. These results concerning harvest index also suggest the possibility of using HI to determine Critical period for weed removal. Yield increased in relation to increase in size of leaf area, this result corresponds to information reported by Lahai *et al.* (2011) that, cultivars with good leaf area and canopy contribute to the storage root yield. Therefore, to get recognizable yield, weed management in cassava is compulsory.

The rapport between root yield and weed biomass was a moderate downhill (negative) relationship (-0.5), root weight was decreasing with increase in weed biomass. To minimize losses caused by weeding cassava, effective weed control is necessary in all districts and in all varieties.

Another variable which was affected by weeds hence leading to yield loss was the leaf area index (LAI). This is the ratio of the leaf surface area to ground area. LAI can help to predict growth. According to the results, the LAI index was increasing with growth (Table 20) in weed free plots, but it was decreasing in weed infested according to time of infestation with weeds. Toward the dry season in May and June (168DAP) the LAI was decreasing, this could be due to high competition for moisture and could also be due to absence of rainfall leading to low moisture, because toward May and June rainfall declined. This reveal that toward dry season and under moisture stress cassava leave shrinks and shade hence affecting the growth. In weed infested the leaf area was dropping this could be due to high competition for moisture between weed and cassava. The indirect effect of weeds toward yield loss was the effect of weeds on leaf area, hence less percentage of light leading to poor photosynthesis and hence less accumulation of dry matter. Similar observation was reported by Silva *et al.* (2013) when working on

determination of competitive ability of cassava with weeds. However, the LAI in weed free set was smaller than LAI in weed infested set, this was caused by variation on ground area. Ground area covered by plant is direct proportional to the plant canopy. The plant canopy in weed free were bigger than canopy in weed infested because of less competition for nutrients. The presence of weeds reduced the spacing of plants, by reducing the spacing of plants, the plants developed apical dominance in search of solar radiation as the result they produced few lateral shoots hence small canopy then small ground area as also observed and reported by Streck (2014). Therefore, leaf area index is an important variable in the study of cassava growth.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Cassava growing areas of Chongwe and Kaoma districts in Zambia comprises numerous types of weed species (40 in Chongwe and 33 in Kaoma identified) encompassed in 15 families in Kaoma and 14 families in Chongwe; subsequently, weed species diversity index was 2.12 to 3.487 (Shannon diversity index) in Kaoma and Chongwe respectively which is high when compared to the typical values of 1.5 to 3.5 in most ecological studies. Evenness in Kaoma was toward completeness because their value ranges between 0 and 1, with 1 being complete evenness.

The critical period for weed removal in the three cassava varieties commonly grown in the Chongwe and Kaoma is between 42 -105 days after planting (Mweru, 42-84 DAP, Nalumino, 42-84 DAP and Chila, 42-105 DAP). Despite of being semi branched variety, Chila need more days of weed free compared to the other varieties.

Yield losses in cassava as the result of weed infestation went as high as 99.99%. Losses were increasing depending on the time coexistence between the crop and weeds. The more the time of coexistence was, the more the weed biomass and the more the yield losses. When the crop was free from weed for 42 days the losses were 88%. When cassava coexisted with weeds for less than 42 days the losses were not significant. Cassava root yield 6 months after planting in weed free plots was significantly higher (17.86 t $ha^{-1)}$ than in weed infested treatments (0.02 t ha^{-1}). Insignificant losses are observed when cassava field are kept weed free all the time.

6.2 Recommendations

i. This research has documented different weed species; therefore, these generated databases should be used in the process of planning weed management programmes, especially that aim at recommending the best weed management technique.

ii. Famers should keep cassava field weed free for the first 105 days of cassava growth in order to reduce significant effect caused by weed competition which is highly experienced in cassava.

iii. Weed removal in cassava is a necessary practice to avoid yield losses. One technique to manage weeds is screening best herbicides for weed control in cassava. Therefore, research on herbicides screening is recommended, and it is the demand driven as expressed by farmers in one of their opinions. The use of herbicides can serve time spent in weeding and will also reduce the drudgery work associated with hand weeding in cassava fields.

iv. Other recommendations: Further studies on weed seed bank should be embarked on, and it will add value when postulating appropriate weed management plans. Furthermore, the study and understanding the weed species entering in the fields and the means of dispersal is important because it may help for future strategies concerning weed management. Moreover, further studies should be conducted to determine the number of economically viable weedings needed in cassava production in the locations.

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APPENDICES

Appendix 1: Survey questionnaire on weed density and diversity

SURVEY QUESTIONNAIRE
Weed Density and Diversity

Introduction:
The objective of this questionnaire is to get information related to **Effects of Weeds in Cassava and How Farmers Manage Weeds in their Cassava Fields**. The information will be compared to the on-going research on the Effects of Weed density and species diversity in Cassava Yield which is carried out in Kaoma and Chongwe, Zambia. Therefore, correct information is required to get relevant and good data to accomplish the study. Your voluntary consent in participating this interview is highly appreciated and the information given will remain confidential.
Thank you
Joseph Nzunda
MSc student (SUA), Research under IITA (International Institute of Tropical Agriculture).

Enumerator's Name: _____
Phone: _____Date: _____Starting Time_____

A. **Part A. Identification /Background** (*Fill the blank, circle or tick √ where appropriate*)

A01.Province: _____
A02.District: _____A03.Area_____
A04 Camp: _____ A05 Village: _____
A06.Type of House Hold (HH) _____1= Female headed 2= Male headed, 3= Headed by both
A07.Name of the head of House Hold(HH)_____
A08.Name of the responded (if not different from head of HH write "same") _____
A09.Age: …….
A10.Sex: _____ (1=Male, 2= Female)
A11.Education_____ (1=Tertiary, 2=Higher secondary, 3=Lower secondary, 4=Primary, 5=None
A12.Marital Status_____ (1=Married, 2=Divorced, 3=Widowed, 4=Single)
A13.Work: _____
A14.Telephone_____

Part B: Cassava Field and Yield *(Tick or circle where appropriate)*

B01	B02	B03	B05	B06(a)	B07
Total Field owned by HH (in Acre) 1= less than 1 2= 1-2 ……. 3= 3-5.…. 4= More than 5…	Cassava Field history: 1= recently cleared from bush 2 = Cultivated for a long time(more than one farming season) 3= Cultivated with cassava last season 4= not cultivated last season ……	Field cultivated for cassava Size in Acre 1=less than 1 2= 1-2 3=3-5 4= More than 5	Number of cassava field owned by HH 1=One field 2=Two fields 3=Three fields 4=Four Fields 5=More than 5 fields	Varieties planted 1= Mweru 2= Chila 3= Nalumino 4= Kampolombo 5=Tanganyika 6= Bangweulu 7= Kapumba 8= Others…… B06 (b) Types of varieties 1=Improved 2=Local.....	Why do you prefer this Variety? 1=High yield 2=Sweet 3=Disease resistant. 4=Others

B08. What are the most important factors that determine how large your cultivated cassava field is in any season? (Tick *where appropriate in order of importance*)

Factor	Very important	Important	Less import
1. Expected family labour availability	……	……	……
2. Cash availability to hire labour	……	……	….
3. Expected tuber prices after harvest	……	……	……
4. Availability of cassava cuttings	……	……	……
5. Availability of fertilizer	…….	……	…..
6. Household food needs	……	……	……
7. Other……	……	……	……
			……
			……

Part C: Cropping System and Cassava Production

Tick or circle where appropriate

C01. Cropping system: 1= Sole 2= Mixed	C02. Agricultural activities 1=Crops, 2=Live stocks 2.1=poultry,2.2 =Goats, 2.3= Sheep, 2.4=Cattle 2.5=Others (mention)……	C03. Most important food crops grown? ▪ Cassava… ▪ Maize…. ▪ Rice……. ▪ Sorghum…. ▪ Others.....	C04. Most important cash crops grown?	C05. Which crop is increasing in importance over the last 5 years? ....
C06. Uses of cassava 1=Food 2=Selling 3=Others…	C07. How do you rank cassava importance in your family? 1=Very important 2=Important, 3=Average, 4=Not important.....	C08. Do you apply fertilizer in cassava? 1=Yes 2=No	C09. Which fertilizer do you apply? …… …… ……	C10 Distribution of farmland (size in acres): a. Plot Abandoned… b. Under fallow… c. Crop type and size Crop 1……. Crop .2……

				Crop 3..... crop 4…….

C11. How do you plant cassava? 1= On flat land… 2= On ridges 3= Others ……	C12.Do you intercrop? 1= Yes 2=No 2 If the answer is 'No' go to C15	C13. Cassava with what? 1=Maize,2=Sorghum 3= 4= 5= 6=Others How do you intercrop? Go to C14	C14.Cropping system 1=Inter-row 2=mixed randomly	C15 Other activities for source of income …… …… ……

Part D: Weed Management In Cassava Fields (circle or tick √)

D01. Weeding techniques 1=Hand hoe 2=Chemicals 3=Combination 4= Others…… ……	D02. When do you start weeding? (Weeks after planting) 1=After one week 2=2 week 3=3 weeks 4….5…… 6….7….8…… Other(mention) …….	D03. How many times do you weed per season? 1=Once 2=Twice 3=Thrice 4….,5…… 6….7…. 8……. others	D04. When you stop weeding? Month after harvesting 1…., 2…. 3...., 4……. 5…., 6…. 7…, 8…..	D05. Which Weeds are most serious in your farm? (rank) …… … ……. ……. ……. …… …	DO5 Which crop need more attention in weeding? 1= Cassava 2= Maize 3……... …… D05 (b) Why? .....

D06.How necessary is weeding in cassava? 1=Very necessary 2=Necessary 3=Not Necessary 4=Don't know	D07. Do all farmers in this community control weed in Cassava? 1=Yes, 2 = No How? 1=Manually 2=Use Chemical 3=Combination

D08. What is your main source of labour for the various operations in your cassava field?

Operation	Family 1=Yes, 2=No	Hired 1=Yes, 2=No	Communal 1=Yes,2=No	Estimated cost
a. Land preparation (Manual)				
b. Land preparation (Draught)				
c. Land preparation (Tractor)				
d. Planting				
e. Weeding				
f. Fertilization				
g. Harvesting				

D09. Which challenges do you face in cassava production?

1= …….....

2= …….....

3=……...

D09 What is your opinion as far as cassava production and weed problem in cassava is concerned? …….....

Thank you very much for your cooperation

Do you have any question for me?

Appendix 2: Formulas used for weeing density and species diversity analysis

Density

The density of each species in each field

$$Dki = \frac{\sum zj}{n}$$

$D_{ki} = \frac{\sum z_j}{n}$ Where D_{ki} is density (number of plants /0.25m^2) of species $_k$ in the field $_i$, $_{zj}$ =number of plants in each 0.25m^2 sample, n is the Number of field

Frequency

This is the ratio of the number of fields where the species was present, to the total number of fields

$F_k = \frac{\sum Yi}{n}$ x100, where $F_k$is the frequency of the species k, *Yi* = presence (1) or absence (0) of the species *k* in field *i* and *n* number of fields

Percentage of frequency of weed families: This was obtained to determine which weed family had more percentage of dominancy. It was calculated by summing the frequency of weed species in each family, dividing it to the sum of the frequency of all families observed and then multiplied by 100

$$of\ family\ frequency = \frac{\sum of\ frequency\ of\ all\ weed\ species\ per\ family}{\sum of\ frequence\ of\ all\ weed\ sepcies\ observed} x100 \quad \text{.....(4)}$$

Uniformity

This is the average percentage of samples from each field in which a given species is present, it was calculated by using the formula

$U_k = \frac{\sum\sum xij\ x\ 100}{10n}$ where Uk is the Coefficient of uniformity of the species, X_{ij} mean present (1)or absent (0) of the species in the sub-sample $_j$ in the field $_i$ and *n* is the number of fields.

Mean Field Density (MFD_k)

The mean field density (MFD) value indicates the number of weeds obtained per square meter for each species averaged over all fields sampled

$MFD_k: = \frac{\sum Dkj}{n}$ where *n* is the number of fields……..(5)

Mean Infested Field Density (MIFD)

The density value referring to the number of fields where the species was present

$MIFD_{k=} \frac{\sum Dkj}{n-a}$ where $_n$ = total number of fields and *a* is the number of fields in which the species was absent

Index of Relative Abundance (RA)

The relative importance value, is an overall evaluation of the importance of each species in respect to others. this was calculated as:

$RA_K = RF_K + RU_K + RD_K$. where RA_K is the relative abundance of species k.

To determine RA_k individual values for RF_K, RU_K, and RD_k it was calculated using the following formulas

$RF_K = \frac{The\ frequency\ of\ species\ k\ x\ 100}{Sum\ of\ all\ frequencies\ of\ all\ specis}$ ……(6)

$RU_K = \frac{The\ uniformity\ of\ species\ \ of\ species\ k\ x\ 100}{Sum\ of\ all\ uniformity\ of\ all\ specis}$ ……..…(7)

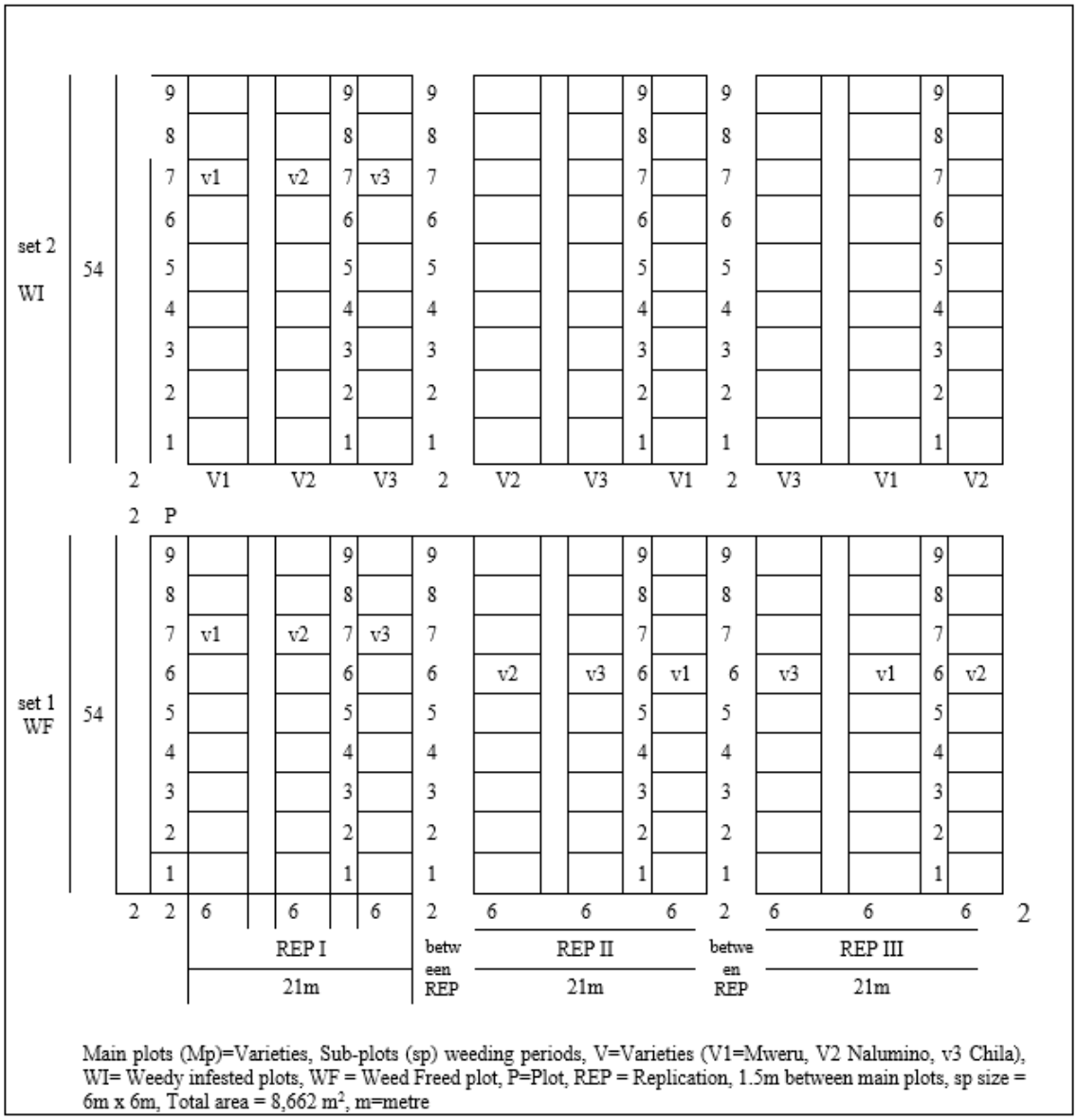
$RD_{K=} \frac{Mean\ density\ \ of\ species\ k\ x\ 100}{Sum\ of\ all\ mean\ densitis\ of\ all\ specis}$ ……..……(8)

Diversity

The estimation of species weed diversity was done by using Shannon Wiener Index H' as follows:

H' = $-\sum_{i-1}^{n} pi \ln pi$ this was described as H'= sum [(pi) x ln (pi)] where, pi=number of individuals of species i/total number of samples, SUM=Summation, S = Total number of species or species richness, ln=Natural logarithm, Evenness (E) = H'/lnS, H' = diversity

Appendix 3: Field lay out



Main plots (Mp)=Varieties, Sub-plots (sp) weeding periods, V=Varieties (V1=Mweru, V2 Nalumino, v3 Chila), WI= Weedy infested plots, WF = Weed Freed plot, P=Plot, REP = Replication, 1.5m between main plots, sp size = 6m x 6m, Total area = 8,662 m^2, m=metre

Appendix 4: Experimental field plan

REPLICATION	Main Plot (MP)	Variety (Factor A)	Sub-plot (sp)	Treatment (Factor B)	WF or WI for… days till harvest
1	1	Mweru	1	1	21DAP
1	1	Mweru	2	6	126DAP
1	1	Mweru	3	8	168DAP
1	1	Mweru	4	3	63DAP
1	1	Mweru	5	4	84DAP
1	1	Mweru	6	5	105DAP
1	1	Mweru	7	7	147DAP
1	1	Mweru	8	9	CONTROL
1	1	Mweru	9	2	42DAP
1	2	Nalumino	1	3	63DAP
1	2	Nalumino	2	9	CONTROL
1	2	Nalumino	3	7	147DAP
1	2	Nalumino	4	1	21DAP
1	2	Nalumino	5	5	105DAP
1	2	Nalumino	6	8	168DAP
1	2	Nalumino	7	2	42DAP
1	2	Nalumino	8	6	126DAP
1	2	Nalumino	9	4	84DAP
1	3	Chila	1	9	CONTROL
1	3	Chila	2	5	105DAP
1	3	Chila	3	2	42DAP
1	3	Chila	4	6	126DAP
1	3	Chila	5	7	147DAP
1	3	Chila	6	1	21DAP
1	3	Chila	7	4	84DAP
1	3	Chila	8	3	63DAP
1	3	Chila	9	8	168DAP
2	1	Nalumino	1	8	168DAP
2	1	Nalumino	2	6	126DAP
2	1	Nalumino	3	2	42DAP
2	1	Nalumino	4	1	21DAP
2	1	Nalumino	5	5	105DAP
2	1	Nalumino	6	4	84DAP
2	1	Nalumino	7	9	CONTROL
2	1	Nalumino	8	3	63DAP
2	1	Nalumino	9	7	147DAP
2	2	Chila	1	2	42DAP
2	2	Chila	2	1	21DAP
2	2	Chila	3	9	CONTROL
2	2	Chila	4	6	126DAP
2	2	Chila	5	8	168DAP
2	2	Chila	6	7	147DAP
2	2	Chila	7	4	84 DAP
2	2	Chila	8	3	63DAP
2	2	Chila	9	5	105DAP

Replication	Main Plot (MP)	Variety (A)	Sub-plot (sp)	Treatment (B)	WF or WI for these days till harvest
2	3	Mweru	1	5	105DAP
2	3	Mweru	2	8	168DAP
2	3	Mweru	3	4	84DAP
2	3	Mweru	4	7	147DAP
2	3	Mweru	5	3	63DAP
2	3	Mweru	6	6	126DAP
2	3	Mweru	7	9	CONTROL
2	3	Mweru	8	2	42DAP
2	3	Mweru	9	1	21DAP
3	1	Chila	1	4	84DAP
3	1	Chila	2	5	105DAP
3	1	Chila	3	7	147DAP
3	1	Chila	4	3	63DAP
3	1	Chila	5	8	168DAP
3	1	Chila	6	9	CONTROL
3	1	Chila	7	1	21DAP
3	1	Chila	8	2	42DAP
3	1	Chila	9	6	126DAP
3	2	Mweru	1	1	21DAP
3	2	Mweru	2	9	CONTROL
3	2	Mweru	3	6	126DAP
3	2	Mweru	4	4	84DAP
3	2	Mweru	5	2	42DAP
3	2	Mweru	6	8	168DAP
3	2	Mweru	7	7	147DAP
3	2	Mweru	8	5	105DAP
3	2	Mweru	9	3	63DAP
3	3	Nalumino	1	8	168DAP
3	3	Nalumino	2	7	147DAP
3	3	Nalumino	3	2	42DAP
3	3	Nalumino	4	5	105DAP
3	3	Nalumino	5	4	84DAP
3	3	Nalumino	6	1	21DAP
3	3	Nalumino	7	3	63DAP
3	3	Nalumino	8	6	126DAP
3	3	Nalumino	9	9	CONTROL

Appendix 5: Analysis of variance

ROOT Weight WF C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.8823	0.4411	5.82	
Variety	2	1.0666	0.5333	7.04	0.049
Error (a)	4	0.3031	0.0758	0.13	
WF or WI Period	8	80.6333	10.0792	17.15	<.001
Variety * WF or WI Period	16	4.0894	0.2556	0.43	0.965
Error (b)	48	28.2048	0.5876		
Total	80	115.1796			

Root weight WI_C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.8521	0.9261	11.28	
Variety	2	0.8056	0.4028	4.91	0.084
Error (a)	4	0.3283	0.0821	0.34	
WF, WI Period	8	148.1625	18.5203	77.67	<.001
Variety * WF or WI Period	16	3.7495	0.2343	0.98	0.490
Error (b)	48	11.4462	0.2385		
Total	80	166.3442			

Harvest Index (HI) WF C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.025068	0.012534	4.36	
Variety	2	0.075792	0.037896	13.17	0.017
Error (a)	4	0.011509	0.002877	0.31	
WF, WI Period	8	1.654510	0.206814	22.12	<.001
Variety * WF or WI Period	16	0.122325	0.007645	0.82	0.660
Error (b)	48	0.448869	0.009351		
Total	80	2.338072			

Harvest index WI_ C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.006209	0.003105	0.93	
Variety	2	0.101323	0.050662	15.14	0.014
Error (a)	4	0.013387	0.003347	0.59	
WF, WI Period	8	2.950680	0.368835	65.50	<.001
Variety * WF or WI Period	16	0.109219	0.006826	1.21	0.294
Error (b)	48	0.270307	0.005631		
Total	80	3.451126			

Leaf area (LA) WF C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	3766.8	1883.4	76.44	
Variety	2	11997.7	5998.9	243.45	<.001
Error (a)	4	98.6	24.6	0.08	
WF, WI Period	8	48833.5	6104.2	21.05	<.001
Variety * WF or WI Period	16	6334.9	395.9	1.37	0.199
Error (b)	48	13918.2	290.0		
Total	80	84949.6			

Leaf area WI C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	3439.4	1719.7	1.32	
Variety	2	268.4	134.2	0.10	0.905
Error (a)	4	5222.3	1305.6	2.02	
WF, WI Period	8	71230.3	8903.8	13.74	<.001
Variety * WF or WI Period	16	5338.2	333.6	0.52	0.926
Error (b)	48	31095.8	647.8		
Total	80	116594.5			

Root weight W K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.1183	0.0592	0.23	
Variety	2	1.5977	0.7988	3.08	0.155
Error (a)	4	1.0385	0.2596	2.12	
WF, WI Period	8	4.6952	0.5869	4.80	<.001
Variety * WF or WI Period	16	0.9293	0.0581	0.47	0.948
Error (b)	48	5.8750	0.1224		
Total	80	14.2540			

Storage root weight WI_K

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.11782	0.05891	0.30	
Variety	2	0.93649	0.46825	2.38	0.208
Error (a)	4	0.78677	0.19669	2.41	
WF_period	8	34.30966	4.28871	52.62	<.001
Variety.WF_period	16	1.98091	0.12381	1.52	0.132
Error (b)	48	3.91211	0.08150		
Total	80	42.04376			

Root girth WF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	28.14	14.07	0.22	
Variety	2	722.61	361.30	5.69	0.068
Error (a)	4	253.87	63.47	1.40	
WF, WI Period	8	2852.53	356.57	7.88	<.001
Variety * WF or WI Period	16	427.12	26.70	0.59	0.876
Error (b)	48	2171.30	45.24		
Total	80	6455.57			

Root girth WI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	29.78	14.89	0.22	
Variety	2	560.58	280.29	4.18	0.105
Error (a)	4	268.26	67.06	1.22	
WF, WI Period	8	13216.52	1652.06	30.05	<.001
Variety * WF or WI Period	16	460.54	28.78	0.52	0.921
Error (b)	48	2639.12	54.98		
Total	80	17174.81			

Root length WF

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	398.6	199.3	19.06	
Variety	2	1266.5	633.2	60.56	0.001
Error (a)	4	41.8	10.5	0.10	
WF, WI Period	8	7614.2	951.8	8.89	<.001
Variety * WF or WI Period	16	1769.5	110.6	1.03	0.442
Error (b)	48	5140.9	107.1		
Total	80	16231.6			

Root length WI

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	52.32	26.16	0.11	
Error (a)	2	7.14	3.57	0.02	0.985
Residual	4	929.23	232.31	2.64	
WF, WI Period	8	27162.25	3395.28	38.55	<.001
Variety * WF or WI Period	16	2051.75	128.23	1.46	0.157
Error (b)	48	4227.11	88.06		
Total	80	34429.80			

Weed biomass WF_

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.498	0.749	0.09	
Variety	2	21.485	10.743	1.25	0.379
Error (a)	4	34.462	8.615	1.37	
WF, WI Period	8	2777.940	347.242	55.06	<.001
Variety * WF or WI Period	16	82.961	5.185	0.82	0.655
Error (b)	48	302.732	6.307		
Total	80	3221.078			

Weed biomass WI C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	657.36	328.68	1.24	
Variety	2	436.95	218.47	0.82	0.501
Residual	4	1060.25	265.06	4.03	
WF, WI Period	8	6551.91	818.99	12.46	<.001
Variety * WF or WI Period	16	1025.65	64.10	0.98	0.497
Error (a)	48	3155.16	65.73		
Total					

Leaf area index WF C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	1.0892	0.5446	4.44	
Variety	2	1.5156	0.7578	6.18	0.060
Error (a)	4	0.4909	0.1227	0.85	
WF, WI Period	8	0.8977	0.1122	0.78	0.622
Variety * WF or WI Period	16	2.5441	0.1590	1.11	0.376
Error (b)	48	6.8991	0.1437		
Total	80	13.4366			

Leaf area index WI C

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Replication	2	0.2711	0.1356	2.45	
Variety	2	0.0957	0.0478	0.87	0.487
Error (a)	4	0.2212	0.0553	0.43	
WF, WI Period	8	1.1934	0.1492	1.17	0.338
Variety * WF or WI Period	16	2.6802	0.1675	1.31	0.229
Error (b)	48	6.1287	0.1277		
Total	80	10.5902			

T-test

Weed biomass Chongwe and Kaoma

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
Weed biomass Chongwe	81	5.508	40.26	6.345	0.7050
Weed biomass Kaoma	81	3.679	13.10	3.619	0.4021

Test statistic t = 2.25

Difference of means: 1.829

Standard error of difference: 0.812

95% confidence interval for difference in means: (0.2232, 3.435)

Test statistic F = 3.07 on 80 and 80 d.f.

Probability (under null hypothesis of equal variances) < 0.001

The test of null hypothesis that mean weed biomass from Kaoma and Chongwe are equal the probability was 0.026

Appendix 6: Determination of Phosphorus in Soils by Spectrophotometry

Bray 1-P Extractant (Bray & Kurtz, 1945), 0.025 M HCl; 0.03 M NH4F
An acidified solution of ammonium molybdate containing ascorbic acid and antimony is added to a sample. The phosphate in the soil sample reacts with the acidified ammonium molybdate to form an ammonium molydi-phosphate complex. A blue coloured solution is generated from the reduction of the ammonium molydi-phosphate complex by ascorbic acid. The intensity of the blue colour is proportional to the amount of molybdo-phosphorus present. Antimony potassium tartrate accelerates the colour development and stabilizes the color for several hours. (12 hrs)
Spectrophotometry
One useful and often used way of determining the concentration of a chemical in a solution, if it has a colour, is to measure the intensity of the colour and relate the intensity of the colour to the concentration of the solution. Spectrophotometric assays use reagents that undergo a measurable colour change in the presence of the analyte.
Procedure -Phosphorus

- Clean the polyethylene bottles with distilled water and weigh 2.5g of the soil sample.
- Dispense 25ml of the extracting solution in the samples and shake for one minute.
- Set the micro beakers with the filter papers and filter the soil sample until a clear filtrate is obtained and pipette 5ml of the filtrate into a 50ml micro beaker.
- Dispense 10ml of reagent B and add 35ml of water. The solution sample is left for 10minutes to react before reading.

Phosphorus standards
The spectrophotometer must be calibrated before analysing the samples.
The prepared standards are 0.1ppm, 0.2ppm, and 4.0ppm. From the 1ppm phosphorus, pipette 0ml, 5ml, 10ml and 20ml respectively. 10ml of reagent Bis add to each beaker. The samples are filled to the mark with distilled water to 50mls and read after 10minutes to allow for the colour to develop before calibrating the spectrophotometer and reading the unknown samples. Calibration is done by using the reference substance –These are the ones used for the calibration curve.

Calculations
The amount of phosphorous in the samples is calculated by subtracting the blank from the obtained result and multiplying by the dilution factor to get the Phosphorous or Boron levels in the sample.
P= (Reading –Blank) * Total dilution factor

pH Determination

The pH determination is a measure of hydrogen ion (H^+) activity in the soil solution. Formally defined, it is:

pH= -Log (H^+)
The concept of pH is thus defined as the negative logarithm to base 10 of the Hydrogen ion concentration.
Procedure:
pH in the lab is done using the electrometric method. This involves the use of a hydrogen sensitive electrode (Glass electrode) together with a reference electrode (Forming a half cell). The glass electrode develops changes in potential (Voltage) proportional to the logarithm of changes in the activity of hydrogen ions (H^+).
The procedure or standard approach for fertility purposes in Zambia measures pH on a 1:2 V/V basis in 0.01M $CaCl_2$.
The pH is measured by inserting the electrodes in the soil/$CaCl_2$ mixture. The calibration of the instrument is calibrated using available Buffer solutions (Usually Buffer pH7 and Buffer pH4).

Procedure

- Weigh 30gms of air dry soil into 100ml beaker
- Add 60ml of $CaCl_2$ solution
- Allow soils to absorb the suspension medium then stir thoroughly for 10 seconds using a glass electrode
- Leave soil samples overnight for homogenization.
- Stir the samples before reading them.
- Read samples after homogenization by first calibrating pH meter with the available buffer solutions (pH4 and pH7)
- Read an internal soil standard sample as a check
- Record pH results.

Kjeldahl Technique- Nitrogen In Soils

The kjeldahl method is a means of determining the nitrogen content of organic and inorganic substances introduced by Johan Kjeldahl . The Kjeldahl method may be broken down into three main steps:

Digestion - the decomposition of nitrogen in organic samples utilizing a concentrated acid solution. This is accomplished by boiling a homogeneous sample in concentrated sulphuric acid at 410ºC. The sulphuric acid (concentrated) helps in the oxidation of organic matter so as to convert organic nitrogen to ammonium nitrogen. The digestion is done with a catalyst (kjeldah tab) consisting of sodium sulphate (Na_2SO_4) for temperature increment as well as copper or selenium which increases the rate of oxidation of organic matter by sulphuric acid.
The end result is an ammonium sulphate solution or converting organic nitrogen to ammonium nitrogen. A general equation for the digestion of an organic sample is shown below:

Organic N + H_2SO_4 → $(NH_4)2SO_4$ +H_2O +CO_2 +Other sample matrix by-products

Distillation - adding excess base to the acid digestion mixture to convert NH4+ to NH3, followed by boiling and condensation of the NH_3 gas in a receiving solution. The liberated NH_3 by distillation of the digest with strong NaOH is collected in a methyl red or methylene blue indicator in boric acid.

Ammonium Sulphate $(NH_4)_2SO_4$ + 2NaOH → ammonium gas $2NH_3$ ↑ + Na_2SO_4 + $2H_2O$

Titration - to quantify the amount of ammonia in the receiving solution. The amount of nitrogen in a sample can be calculated from the quantified amount of ammonia ions in the receiving flask.
The use of H_3BO_3 solutions containing the titration indicator has an advantage in that it serves as an indicator solution sever to indicate if the neutralisation of NH_3 is complete. The amount of Nitrogen is calculated as shown below

$$\%Nitrogen = \frac{(ml\,standard\,acid - ml\,blank)\,x\,N\,of\,acid\,x\,1.4007}{weight\,of\,sample \in grams}$$

………………………………..(9)

Procedure

1. Weigh 5g of soil and put in the digestion tubes using an analytical balance
2. Add the kjeldahl catalyst powder/ kjeldahl tab to each one of the digestion tubes with the samples to be analysed
3. Add 20ml concentrated sulphuric acid and mix by swirling the tube by hand or by using a

test tube mixer.

4. Place the digestion tubes in preheated digestion block and heat samples at 420 degrees Celsius till sample turns green (About 3Hrs)
5. leave and cool in the fume hood on the stand
6. Measure 20mls boric acid solution into the receiver conical flasks corresponding to the number of digestive tubes used
7. Place the receiver flask in the upper position on the platform of the distilling unit
8. Fix the prepared digestion tube to the corresponding tube holder and add NaOH and start the distillation - set the distillation time
9. When the distillation is complete, remove digestion tube and rinse then put back on the tube rack.
10. Remove the receiver flask with the green solution and titrate with 0.25N HCl to purple, the colour of boric acid.
11. Calculate the amount of Nitrogen in the sample.

Determination of Organic Carbon in Soils
Walkley Black

Walkley-black method is based on the oxidation of soil organic carbon by Potassium dichromate ($K_2Cr_2O_7$) in sulphuric acid. A known amount of dichromate is added and when the reaction is finished, an excesses dichromate not reduced by the organic matter is determined by titration with ferrous sulphate.

$C + 2O$ --------CO_2

Dehydration of carbon

$3C + 2Cr_20_7^{2-} + 16H^+$----------$4Cr^{3+} + 3C0_2 + 8H_20$

Oxidation of carbon can be written as above, assuming all the carbon is oxidised and then 1 mole of dichromate reacts with 1.5mole or 18g of carbon

1ml 1M $K_2Cr_20_7$ = 18mg C

PROCEDURE

1. Weigh exactly 1g of the grind samples into an Erlenmeyer flask
2. Add 10mls of potassium dichromate
3. Add 20mls of conc sulphuric acid and leave for 30mins for digestion in the fume hood
4. Add 200mls of distilled water with a measuring cylinder
5. Dispense 10mls of phosphoric acid into the Erlenmeyer flasks and swirl to mix the contents
6. Add 1 or 2 drops of diphenylamine indictor swirl to mix the contents.
7. Fill the semi-automatic burette with ferrous sulphate solutions.
8. Titrate with ferrous sulphate

CALCULATIONS

To calculate the organic matter contents of the soil, subtract the titrate from the blank then multiply by a value of 0.31551 to get the C%

Calcium, Magnesium, Potassium and Sodium
Ammonium Acetate Extraction

Principle of the Method

This method uses 1N ammonium acetate (NH4OAc) bufferedat pH 7.0 to extract basic cations (calcium, Ca; magnesium, Mg; potassium, K and sodium, Na) from the soil. The quantity of extracted basic cations is equivalent to the quantity considered exchangeable. The ammonium ion replaces the basic cations by cation exchange. Ammonium is selected as a replacing ion because of the relatively low levels of exchangeable ammonium in most arable soils, and because the quantity of cations extracted by ammonium acetate reaches a relatively stable quantity after a

short period of time. The acetate buffers suspensions near a desirable level of acidity for most crops.

The method employed in the extraction of Calcium, Magnesium, Potassium and Sodium ions from the soil involves leaching an accurately weighed sample of soil with a known volume of Ammonium acetate (CH_3COONH_4) solution of a known concentration (1Normal) as an extracting solution. The principle on which this method works is ion exchange. The ammonium ion, NH_4^+, from ammonium acetate in the extracting solution readily exchanges for Ca^{2+} , Mg^{2+}, K^+ and Na^+ from the soil particles in a chemical process known as cation exchange. The extracted basic cations remain in the collected solution/ leachate or extract as Calcium Acetate, $(CH_3COO)_2Ca$, Magnesium Acetate, $(CH_3COO)_2Mg$, Sodium Acetate,
CH_3COONa, and Potassium Acetate, CH_3COOK.

Procedure

1. Weigh 2.5g of air dried soils
2. Put into a 50mls leaching tube
3. Place the leaching tube in the leaching room and place each 50ml micro beaker under each leaching tube
4. Leach with 25ml ammonium acetate solution
5. Collect filtrate in micro beakers
6. Dilute sample with Lanthanum or Strontium chloride if necessary for Magnesium and Calcium to suppress interferences of phosphates and read using atomic absorption
7. For Potassium and Sodium dilute with water if too high and read using emission or flame photometer

The method involve saturation of the soil with an index cation (NH_4), removal by washing of excess cation with Absolute alcohol (Ethanol/Methanol), and subsequent replacement of the adsorbed index cation by another cation (Na) from Sodium Chloride and measurement of the index cation in the final extract .

The displaced ammonium ions are treated with 40% Sodium hydroxide and distilled using a Kjeltec distiller and the liberated ammonia gas trapped in Boric acid and titrated with 0.25 M Hcl.

Cation exchange capacity is reported as centimoles of positive charge per kg of soil (cmol (+)/kg). The old unit milli-equivalents per 100 g (meq/100g), whereas 1 meq/100 g = 1 cmol (+)/kg), can be used. Values of CEC are in the range of 1.0 to 100 cmol (+)/kg, least for sandy soils and most for clay soils. Similarly, higher CEC values reflect the dominance of 2:1 clay minerals, and lower values reflect the presence of 1:1 clay minerals.

Soil data interpretation

Element	Measurements	Grade levels	Comments
Soil pH (CaCl2)	>7.5 6.5-7.4 5.5-6.4 4.6-5.4 <4.5	Alkaline Neutral Slight acid Medium acid Strongly acid	
Nitrogen (N) (%)	<0.1 0.1-0.20 0.21-0.50 >0.5	Very low Low Medium High	
Phosphorus (P) (ppm)	<10 11-25 20-45 46-65 >65	Very low Low Medium Moderately high Very high	
Potassium (K) (ppm)	<15 15-35 35-105 105-175 >350	Very low Low Medium High	
Organic carbon	<1.58	Low	