ENVIRONMENTAL AND CASSAVA VARIETY INFLUENCE ON DYNAMICS AND IMPACTS OF CASSAVA GREEN MITE, *Mononychellus tanajoa* (Bondar) (Acarina: Tetranychidae) IN TANZANIA

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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EXTENDED ABSTRACT

In Tanzania, cassava (*Manihot esculenta* Crantz) is an integral component of most cropping systems and is among the most important staples in many zones. It is an essential component as a food security crop and provides useful opportunities for extending labour use and sometimes considered as a famine reserve when cereals fail due to its drought tolerance. Cassava is attacked by several pests, among which cassava green mite, *Mononychellus tanajoa* (Acarina: Tetranychidae) is most important. *Mononychellus tanajoa* can cause a reduction of about 50% in leaf weight and up to 80% tuber yield loss. It is therefore a pest that can pose multi–dimensional problems that require multi–dimensional solutions. The current cassava productivity in Tanzania is near the lower end of internationally reported yields. *Mononychellus sp*. was first reported in Tanzania in 1972 at Ukerewe Island. At present cassava green mites have spread throughout the country and are prevalent in all the cassava growing zones of Tanzania. The current study aimed at establishing *M. tanajoa* pest status and distribution in the three major cassava growing zones. It also studied the damage inflicted on some commercial and local cassava varieties and examined the influence of the environment and seasons on the pest in Tanzania. Specifically the study aimed to i) determine the spatial distribution of *M. tanajoa* on commonly grown cassava varieties in the Eastern, Lake and Southern zones of Tanzania ii) evaluate the environmental influence on occurrence and perpetuation of *M. tanajoa* on selected cassava varieties and iii) assess the abundance and associated damage of *M. tanajoa* on commercial and popular cassava varieties in the Lake zone. The studies were conducted in the three major cassava producing zones (Lake, Eastern, and the Southern Zones) of Tanzania. The surveys were conducted in farmers' fields during 2015 and 2016 dry seasons in the three Zones. A total of 5400 plants in 180 fields were assessed during 2015 and 2016 for *M. tanajoa* infestation and associated damages. Collected data were subjected to non-parametric analysis in SPSS and Kruskal-Wallis test was used to compare between the pest counts and distributions. Weather parameters were analyzed against the pest counts and associated damages. Results revealed that *M. tanajoa* counts were significantly ($P \leq 0.05$) varied with the Lake and Southern zones recording the highest numbers compared to the Eastern zone. The assessed cassava varieties significantly ($P \leq 0.05$) influenced *M. tanajoa* counts while cropping systems had no effect on insect counts in both 2015 and 2016. The relationship among the environmental variables, rainfall (β = -0.406, $p \leq 0.0.007$), maximum temperature (β = -14.35, $p \leq 0.010$) except relative humidity (β = -0.0054, $p \leq 0.524$) were significant ($P \leq 0.05$) and negatively related to *M. tanajoa* counts in 2015 while in July 2016, only rainfall (β = -0.1091, $p \leq 0.001$) was significant ($P \leq 0.05$) and negatively correlated to *M. tanajoa*. The survival, perpetuation and distribution of *M. tanajoa* were attributed to the differences in varietal preference, crop age and weather variables. Field experiments were conducted to evaluate the environmental influence on pest occurrence and associated damages at three (3) sites namely Ukiriguru, Ng’ombe (Misungwi district) and Kishiri (Kwimba district) in the Lake zone during the 2014/2015 and 2015/2016 cassava growing seasons. Cassava varieties were established in a Split Plot Design and replicated three times. Treatments included the experiment location (main factor) and varieties (sub-factor) under natural infestation by the mites. Kyaka variety was considered as resistant check to *M. tanajoa*. The findings from this study suggested that location within a zone has limited influence ($P>0.05$) on *M. tanajoa* counts. The highest counts were recorded during the dry season in both years. Young, succulent and actively growing foliage were highly infested compared to the mature and old foliage. Almost all the tested cassava varieties sustained great counts of *M. tanajoa* and were likewise susceptible except Kyaka and Meremeta varieties. The tested weather variables negatively (rainfall) or positively (temperature) affected the survival, perpetuation of and subsequent damages by *M. tanajoa* in both years. The interaction effects of time (months) and locations on *M. tanajoa* damage was significant ($P<0.05$). Another field experiment was set for two consecutive years (2014/2015 and 2015/2016) at Ukiriguru to determine the response of the eight commercial cassava varieties and one local variety (used as susceptible check) to *M. tanajoa*. The experiment was laid out in a completely randomized block design (CRBD) with nine varieties as treatments in three replications. Results indicated that Liongo Kwimba recorded significantly ($P\leq0.05$) highest damage, leaf malformation and subsequently low yield (9.51ton/ha) compared to other varieties especially Kyaka and Meremeta. The least preferred and damaged by the pest, Kyaka variety recorded the highest yield (43.235 ton/ha). Leaf damage and malformation were significantly ($P\leq0.05$) higher in 2016 compared to 2015. Highest leaf damage and malformation were recorded in June to August and the lowest in March to May with varied fluctuations among varieties in the rest on the months. Based on the findings, it was concluded that *M. tanajoa* was present in all cassava growing areas of the country and most of the grown varieties succumbs to the pest. The environment and weather influence on the *M. tanajoa* counts and damages were varied across sites with rainfall and maximum temperature affecting the pest negatively while relative humidity and minimum temperature promoted the pest survival and perpetuation. Most of recently released commercial varieties also succumbed to *M. tanajoa* except Kyaka and Meremeta that were resistant. Therefore, promotion of these varieties across the country will be imperative for improved cassava productivity in Tanzania.

DECLARATION

I Wudil, Sani Baba do hereby declare to the Senate of the Sokoine University of Agriculture that this thesis is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted for a degree award in any other institution.

Baba S. Wudil Date

(PhD Agricultural Entomology Candidate)

The above declaration is confirmed by;

Dr. G. M. Rwegasira Date

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Dr. A. B. Kudra Date

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This work is dedicated to the entire Mai Lemo family, inclusive of my beloved Parents, Late Alh. Sani Yusuf (Father), may his gentle soul rest in Jannatul Firdausil a'ala amen, Hajiya Bilkisu Sani Yusuf (Mother), and my wives, Rahmatu Ibrahim Isma'eel and Zahra'u Hussain Ahmad as well as my children, Maryam, Ai'shat (daughters), Muhammad Awwal and Abubakar Sadeeq (Sons) as well as the entire Mai Lemo family.

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LIST OF ABBREVIATIONS, SYMBOLS AND ACRONYMS

ACARI	Acaridae
ACMD	African Cassava Mosaic Disease
ACMV	African Cassava Mosaic Virus
ANOVA	Analysis of variance
BLD	Belinde cassava variety
BUK	Bayero University Kano
CAD	Cassava Anthracnose Disease
CBB	Cassava Bacterial Blight
CBN	Cassava Bud Necrosis
CBSD	Cassava Brown Streak Disease
CGM	Cassava Green Mite
CIAT	Centro International de Agricultura Tropical
CMB	Cassava Mealy Bug
CMD	Cassava Mosaic Disease
COSCA	Collaborative Study of Cassava in Tanzania
DMRT	Duncan Multiple Range test
DNA	Deoxyribos Nucleic Acid
E	East
FAO	Food and Agricultural Organisations
FAOSTAT	Food and Agricultural Organisations Database
GIS	Geographic Positioning System
GSM	Green Spider Mite
Ha	Hectare

IFAD	International Fund for Agricultural Development
IITA	International Institute of Tropical Agriculture
IPM	Integrated Pests Management
Kg	Kilogramme
KMBA	Kwimba district
KRB	Kiroba cassava variety
KUST	Kano University of Science and Technology
KYK	Kyaka cassava variety
LNG	Liongo Kwimba cassava variety
LSD	Least Significant Difference
LZARDI	Lake Zone Agricultural Research and Development Institute
M	Metre(s)
M. tanajoa	*Mononychellus tanajoa*
MKZ	Mkombozi cassava variety
MRM	Meremeta cassava variety
NGMB	Ng’ombe village
NLD	Naliendele cassava variety
NMK	Namikonga cassava variety
PCR	Polymerase Chain Reaction
RNSTD	Root Number per Stand
RWHA	Root Weight per Hectare
S	South
SAS	Statistical Analysis System
SD	Standard Deviation
SE	Standard Error

Sp	Specie
Spp	Species
SPSS	Statistical Package for Social Science
SRI	Sugarcane Research Institute, Kibaha, Tanzania
SUA	Sokoine University of Agriculture
SUM	Suma cassava variety
TETfund	Tertiary Education Tax Fund of the Federal Republic of Nigeria
UKRG	Ukiriguru village

CHAPTER ONE

1.0 INTRODUCTION AND LITERATURE REVIEW

1.1 Background

1.1.1 World cassava production

The word cassava (*Manihot esculenta* Crantz: Euphorbiaceae) comes from "Casabi", the name given by the Arawaks Indians to the root (FAO and IFAD, 2000), also known ethnically as *yuca* (Spanish), *mandioca* (Portuguese), *tapioca* and *manioc* (French), "cassave" in Dutch and "maniok" in German as well as "Muhogo" in Swahili and "Rogo" in Hausa language is a tropical and subtropical short-lived perennial shrub originated from Latin America, most probably from the Amazon region (Pellet and El-Sharkawy, 1997; FAO and IFAD, 2000; Hillocks, 2002). The crop is believed to be a native of North east Brazil (Allem, 1994) and South and Central America (Carter *et al.*, 1992) where it has been cultivated for the past 2500 years (Cock, 1985). *Manihot* was brought to Africa by the Portuguese in the 16^{th} century and introduced to the East African coast at the end of the 18^{th} century (Carter *et al.*, 1992). It was then spread to the inland from both west and east coasts (Mandal, 1993).

1.1.2 Origin and spread of cassava

Cassava was widely cultivated as a staple crop in pre-Columbian tropical America. Early European traders soon recognized its importance and, in the 16^{th}century, introduced it into Africa (FAO and IFAD, 2000). It was also reported to have been brought from Brazil to the West Coast of Africa by the Portuguese in the 16^{th} Century in the context of their trade triangle between Europe, Latin America and Africa (Zundel *et al.*, 2007). The crop is one of the most common food crops grown and consumed in many parts of Africa and adapts well to various soil types and ecologies (IITA, 1997). More so, it is adaptable to different type of soils and is cultivated under temperature and rainfall conditions varying between 10°C and 40°C and between 900 mm and 2000 mm, respectively (IFAD and FAO, 2000). Subsequently, cassava has been introduced in almost every part of the tropical regions and has become a part of the staple food or subsidiary food item for millions of people in the world (Mandal, 1993). Africa is the main producer of cassava contributing to almost 53% of the world's cassava production followed by Asia at 29% (FAOSTAT, 2014).

Manihot is one of the most cultivated and consumed food crops in many parts of Africa as it adapts well to various soil types and ecologies (IITA, 1997). The stem is used as propagation material from which grows the roots and shoots. Propagation by seeds is used rarely especially during crossing process in breeding or when introducing materials from one ecological zone to another to avoid disease transfer (Olsen *et al*., 1999). Certainly Nigeria benefited from the presence on its territory of the IITA, which played an essential role in the promotion and dissemination of improved cassava varieties. In the rest of the region, wars, civil strife and the resulting economic dislocation prevented major yield improvements from taking place (IFAD and FAO, 2000). Adverse climatic conditions, i.e. prolonged droughts in many parts of Africa, and the recurrence of infestations by the cassava mealy bug (CMB), green spider mite (GSM) and outbreaks of African cassava mosaic virus (ACMV), have also impaired productivity in many areas (IFAD and FAO, 2000). Indeed, it has been estimated that pests, including weeds, reduce yields by almost half, while the African CMVs alone is estimated to lower them between 28% and 40%. However, the danger posed by the CMB, which threatened to wipe out cassava in the 1970s, has been considerably reduced owing to the combined efforts of the

IITA and the Centro International de Agricultura Tropical (CIAT) through technology transfer (IFAD and FAO, 2000).

1.1.3 Cassava production in Africa

In the early 1960s, Africa accounted for 40 percent of world cassava production and Brazil was the world's leading cassava producer. However, thirty years later in the early 1990s, Africa produced half of the total world cassava output and Nigeria replaced Brazil as global leading producing country (FAOSTAT, 2013). Today, it is grown in the so-called cassava belt of Africa, i.e. everywhere between the two Tropics where annual rainfall is at least 500mm. The crop is grown in 39 African countries, of which Nigeria, Democratic Republic of Congo, Ghana, Tanzania and Mozambique are among the top ten producers in the world (FAO, 2001). Currently, Africa is the major producer in the world with average production of 100 million tons annually which is about 53% of the world's production followed by Asia (FAOSTAT, 2014; Ntawuruhunga *et al*., 2007). However, damage caused by the mites drastically affects cassava production in Africa. The two leading cassava producing countries namely Nigeria and Brazil have been reported to suffer serious economic losses from green mites, *Mononychellus tanajoa* Bondar (Acarina: Tetranychidae). The losses in Africa and Brazil are estimated at 80% and 51% respectively (Andre *et al*., 2014).

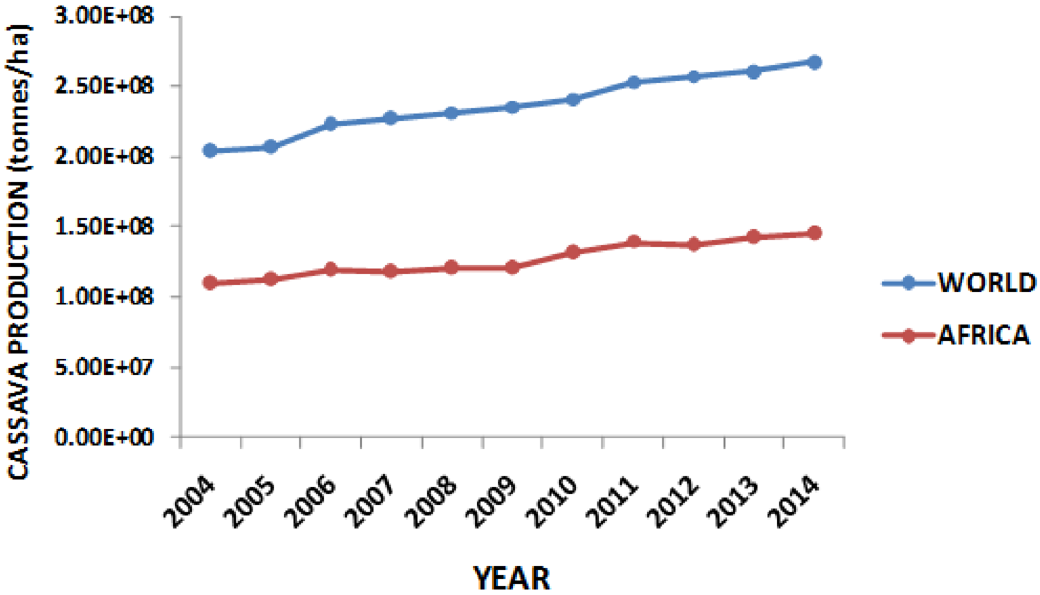

Figure 1.1: World and Africa's Cassava Production Trend from 2004 to 2014 (FAOSTAT, 2014)

1.1.4 Cassava production in Tanzania

Agriculture is the foundation of the Tanzanian economy as it accounts for about half of the national income, three quarters of merchandise exports; and the main source of food and provides employment opportunities to about 80% of the population (Pascal, 2013). The traditional role of cassava in Tanzania and elsewhere in Africa has mainly been in the context of either famine crop or a common source of food energy in forms of flour and starch (FAO, 1998; Nweke *et al*., 1998 and Kapinga *et al*., 2005). The aforementioned dietary and economic importance of cassava has made it to play an important role in food security by providing a stable food base in areas prone to draught and famine (Carter *et al*., 1992).

Tanzania is the fourth producer of cassava in Africa and annual root production is estimated at 5 500 000 tons from 761 100 hectares (Mkamilo and Jeremiah, 2005). It is produced in all the agro-ecological zones and the range of production being in order; Lake zone > Southern > Western > Zanzibar > Eastern > Southern highlands > Central and the Northern zone respectively (Kulembeka *et al*., 1998; Nweke *et al*., 1998; Kapinga *et al*., 2005). Among the cassava producing regions in Tanzania, Mwanza is the main cassava producing region with an average cassava production of 3 million metric tons per annum (MMA, 2007). The crop is one of the most important food crops and the major producing areas are the coastal strip along the Indian Ocean, around Lake Victoria, Lake Tanganyika and along the shores of Lake Nyasa (Mkamilo and Jeremiah, 2005). It is the second most important food crop after maize in terms of production volume and per capita consumption, supporting the livelihood of 37% of farmers in rural areas. Majority of the poorest farmers (59%) are reported to grow the crop for food (Ben *et al*., 2012).

The agricultural sector in Tanzania however, is faced with a multitude of problems among which cassava productivity is near the lower end of internationally reported yields (Kapinga *et al*., 1996). The constraints are: prevalence of devastating pests/diseases, use of varieties with low genetic potential, shortage of planting materials, drought, poor soil fertility; and low adoption rates of research recommendations, leading low cassava productivity in the country and beyond (Kapinga *et al*., 1996).

The crop is attacked by several pests, among which the cassava green mite, *Mononychellus tanajoa* (Acarina: Tetranychidae) is the most important (Évila *et al*., 2012; Moraes and Flechtmann, 2008). *Mononychellus tanajoa* was originally discovered in 1938 on cassava variety *Manihot esculenta* Crantz in Brazil, but its studies began 33 years later when it was found in Uganda, Africa. Despite the continent has a greater knowledge of the species, it still needs further technological development (Andre *et al*., 2014; Noronha, 2001). There are also reports of *M. tanajoa* attacks in the Asian continent, specifically in China, but the magnitude of damages are still not well established (Chen *et al.,* 2010). Nonetheless, *Mononychellus tanajoa* has recently been recorded as a quarantine pest in Hainan, China. The pest had heavily caused damage to cassava growth and led to serious economic losses in some main cassava production areas of China (Hui *et al*., 2012).

According to Lu *et al.* (2012), *M. tanajoa* has rapid dispersal ability, both between countries of the same continent and outside. It quickly infest and colonize its host, which makes the pest present in many places in the world such as Africa, South America, Central America and Asia where it is considered a quarantine pest. It attacks mainly shoots and leaves of cassava reducing both photosynthetic rate and root dry matter (Moraes and Flechtmann, 2008). At present the mites have spread throughout Tanzania, although at variable incidences among agro-ecological zones.

1.1.5 Economic importance of cassava in Tanzania

Cassava is a subsistence food to 200 million people in the African continent and in the Brazil serves as food for millions of poor people and plays an important role in the generation of employment and income, especially for small and medium producers (Andre *et al*., 2014). Cassava is becoming a commercial reserve because of its increased importance as a cash crop. The survey results also showed that about 21% of total sampled households cultivated cassava and 15% of cultivated area by sampled households was planted with cassava (Lazaro *et al*., 2007). The lack of reliable market is partly a factor that limits the potential for cassava production in Tanzania.

Apart from being used as a source of calories to human beings, cassava tubers are also used as livestock feeds (FAO, 1998). Cassava has currently become the major staple food for about 40% of the population in sub-Saharan Africa (Bokanga and Otoo, 1991). The tubers are very rich in starch and contain significant amounts of calcium (5 mg kg^{-1}), Phosphorus (4 mg kg^{-1}) and vitamins C (2.5 mg kg^{-1}) (Olsen *et al.*, 1999; Baguma and Kawuski, 2006). *Manihot* also plays an important role as source of income for a significant number of farm households in parts of the humid tropics where hunger, starvation and unemployment prevail (FAO, 1998; Ayoola and Makinde, 2007). In a survey reported by Lazaro *et al.* (2007), results also showed that about 21% of total sampled households cultivated cassava and 15% of cultivated area by sampled households was planted with cassava.

The current trends indicate that the consumption of cassava is increasing and that the growing of cassava is expanding to other semi-arid areas where cassava was not cultivated 20 years back due to land scarcity (Peter, 2011). The crop is of great importance in the nutrition of over 800 million people in the tropical and sub-tropical countries (Olsen *et al.*, 1999). Despite the increased interest in the crop it should be noted that cassava is a cyanogenic plant and care for the suitable varieties must be of prime importance when used as food. The storage roots can be processed into various food products and starch for domestic consumption, local, and/or export markets. Cassava leaves are nutritious vegetables in some countries (IITA, 1997) and can also be used as animals feed. The shoots produce leaves that constitute a good vegetable for food that is rich in proteins, vitamins (Bokanga and Otoo, 1991) and minerals (Rongjun, 2000). However, the leaves are poor in proteins (1 to 2%) and essential amino acids, particularly lysine, methionine and tryptophan (Okigbo, 1980; Olsen *et al.*, 1999). In contrast, cassava leaves are a good source of proteins if supplemented with the amino acid like methionine (Olsen *et al*., 1999).

1.1.6 Cassava production trends in Tanzania and beyond

The World cassava production increased at a rate of 2.2 percent a year from 1984 to 1994 the same as in the previous decade reaching 164 million tons in 1997 or 60 million tons more than in 1973 to1975 (FAO and IFAD, 2000). Almost 70 percent of world cassava production is concentrated in five countries, namely Nigeria, Brazil, Thailand, Indonesia and the Democratic Republic of Congo (FAO and IFAD, 2000). Cassava production trends and land area expansion in Tanzania have been fluctuating over years. In all major cassava production zones, the production declined in 1985/86 season until 1988/89 season except in the Eastern zone where cassava production increased (Kapinga *et al*., 1996). Cassava yields vary with cultivars, season of planting, soil type and fertility. With improved varieties and under good management practices, up to 20–25 tons per hectare may be attained. Under the most prevalent farming methods, cassava yields are much lower (FAO and IFAD, 2000).

Cassava is an important subsistence food crop in Tanzania, especially in the semi-arid areas and sometimes considered as a famine reserve when cereals fail due to its drought tolerance (Kapinga *et al*., 1996). Up to 84 % of the total production in the country is utilized as human food and the rest is for other uses like starch making, livestock feed and export (Kapinga *et al*., 1996). Both roots and leaves of cassava are of major nutritional importance. The estimated annual growth of cassava consumption demand for the period from 1980 to 2000 was 3.4 %, similar to that of maize. Cassava is cultivated and produced in all regions of Tanzania. The main producing areas are: Mwanza, Mtwara, Lindi, Shinyanga, Tanga, Ruvuma, Mara, Kigoma, Coast regions and most regions in Zanzibar (Mkamilo, 2005).

Tanzania's average cassava fresh root yield is about 8 t/ha (FAO, 2001). This is well below the continent's average of 10 t/ha and the average yield of 14 t/ha of Africa's (and the world's) largest producer, Nigeria (Mkamilo and Jeremiah, 2005). Yields of cassava vary depending on variety, climate, soil type and age at the time of harvest but normally range from 10 – 40 t/ha for improved varieties and 5 – 15 t/ha for local varieties and drop to 3 t/ha for soils of low fertility status (Adupa, 1994). The three years data (1996 – 1998) showed that cassava production in Tanzania has been declining, from 5.7 to 4.5 million tons (FAO, 1998).

Tanzania was among the 10 main African cassava producing countries in the 1980's (Peter, 2011). In 1986 Tanzania ranked 4th with an average production of 1.5 million metric tons and in 1989 it ranked 3rd with average production of 5 million metric tons (FAO, 1998). The trend changed drastically and in 1998 Tanzania ranked 6th (FAO, 1998) with an average production of 6.9 million metric tons. More so, at the rank of 6th position, Tanzania produced 10 t/ha which was below the potential of the crop of 25 to 40 t/ha (FAO, 1998). In a recent study in Tanzania, it was reported that the average yield ranges from 6 – 10 t/ha (MMA, 2007). Based on the data collected in the Lake zone in seven consecutive years in late 1990s the cassava yields have been fluctuating with the lowest yields recorded during the 1999/2000 season (MMA, 2007).

The low yields in Tanzania generally were caused by many factors including pests and diseases, declining soil fertility, moisture stress, accessibility to markets, poor crop husbandry and management practices (Nweke *et al*., 1998; MMA, 2007). The current cassava productivity is near the lower end of internationally reported yields (Kapinga *et al*., 1996). Similarly, estimated losses in yield of cassava roots in Tanzania vary from 50 to 80 percent (Shukla, 1976) depending on the susceptibility of cassava varieties. Other key constraints include the low level of utilization of cassava and poor post-harvest handling techniques of cassava at farm level (Kapinga *et al*., 1996).

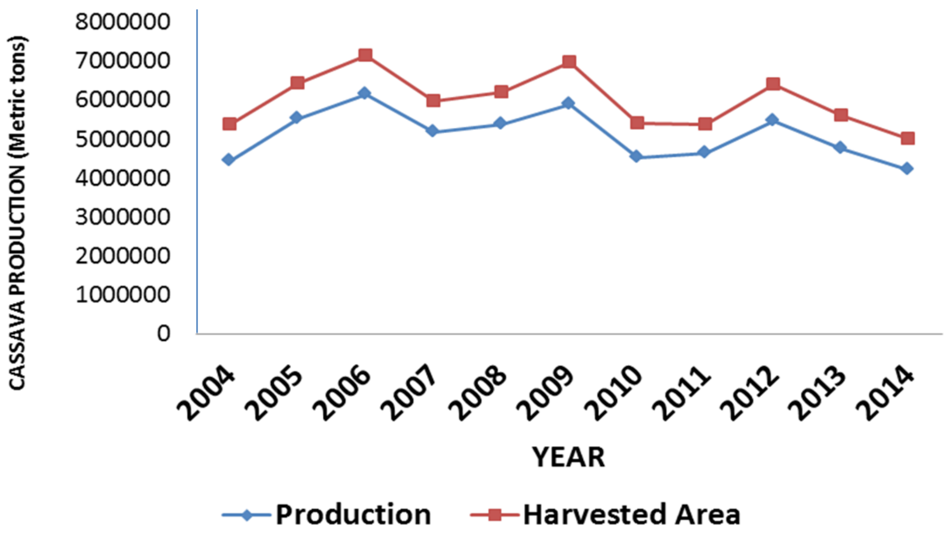

Figure 1.2: Tanzania Cassava Production Trend and Harvested Area from 2004 to 2014 (FAOSTART, 2014)

1.1.7 Limitations to cassava production in Tanzania

The average cassava yield in Tanzania is far below those recorded in other countries in Africa and elsewhere in the world (FAO, 1998; FAOSTAT, 2014; Nweke *et al*., 1998). The low yields are claimed to be due to pests and diseases, poor growing varieties, low soil fertility, as well as unreliable climatic conditions (Kulembeka *et al*., 1998; Kapinga *et al*., 2005). Cassava is affected by a number of pests and diseases that reduce yields drastically (Legg *et al*., 1997; Msikita *et al*., 1997; Moses *et al*., 2005). The most important pests are cassava mealy bug (CMB) (*Phenacoccus manihoti* Matile-Ferrero) and cassava green mite (CGM) (*Mononychellus tanajoa* Bondar) (Legg *et al*., 1997).

According to IITA (1990), although cassava has many benefits as a crop of the tropics, its production faces many constraints leading to low productivity. The constraints include biotic, abiotic and socio-economic factors. Biotic and abiotic constraints include shortage of appropriate improved cultivars with high genetic potential, long growth cycle, inadequate availability of disease-free planting materials, post-harvest losses, nutritional deficiency for people who solely depend on cassava, cyanide content, diseases and pests (IITA, 1990). Furthermore, during planting season, farmers face critical shortage of planting materials, this causes farmers to use any cassava materials readily available in their localities without considering quality of those planting materials which leads to low cassava yields (Lukombo *et al*., 2002). Mtunda (2009) reported the major constraints limiting cassava production and productivity include pests and diseases, poor crop management practices, declining soil fertility, inadequate inputs, erratic weather conditions, limited access to quality planting material and low adoption of improved technologies.

According to Oluwasola (2010) the major constraints to smallholder farmers are scarcity of affordable and environmentally appropriate technologies. Scarcity of appropriate technologies makes smallholder farmers to depend mainly on natural systems for sustenance. Mkamilo and Jeremiah (2005) stated that there are constraints which decrease production of cassava in Tanzania including diseases and inadequacy of planting materials. Most of the varieties grown by farmers have been selected randomly and have low genetic potential for yields and resistance to major pests and diseases.

Among the major diseases are Cassava Brown Streak Disease (CBSD) and Cassava Mosaic Disease (CMD). COSCA Tanzania (1996) pointed out that, lack of improved seed systems, inadequate processing facilities, knowledge, marketing, inadequate capital investment and unavailability of credit facilities also contributed to low cassava productivity in farmers' fields and subsector at large. These problems are caused by lack of favorable policy which favors cassava commercialization (Mkamilo and Jeremiah, 2005).

1.1.8 History of cassava green mite in Tanzania

Cassava green mite (*Mononychellus sp*.) was first reported in the country in 1972 in Ukerewe Island (Msabaha *et al*., 1988). At present cassava green mites have spread throughout the country and are prevalent in all the cassava growing zones of Tanzania. During the period of 1970 – 1989 cassava mottled virus (CMV) was reported to cause severe yield losses but currently is no longer a threat to the Lake zone of Tanzania (Kapinga *et al*., 2005) following the establishment of the Biological Control Centre for Africa at the International Institute for Tropical Agriculture (IITA), (Legg *et al*., 1997). Other common pests and diseases are variegated grasshoppers, sparingly whiteflies, *Bemisia tabaci*, termites and grass cutters while on the other hand the diseases are cassava anthracnose disease (CAD), cassava bud necrosis (CBN), cassava brown streak disease (CBSD), cassava mosaic disease (CMD) and cassava bacterial blight (CBB) respectively (Msikita *et al*., 1997).

1.1.9 Strategies to improve cassava production in Tanzania

The vision for cassava in Africa (Tanzania inclusive) is that if the cassava food system is improved, it will enhance rural industrial development and raise incomes for producers, processors and traders (FAO and IFAD, 2005). Cassava will contribute more to the food security status of its producing and consuming households, and will become an even more important cash crop that can promote rural development (FAO and IFAD, 2005). The analysis presented in a paper by Lazaro *et al*. (2007) show that there is potential for cassava to be a commercial crop for Tanzania rather than just a famine reserve. There is potential for marketing cassava both domestically and abroad. Evidence has shown that with assurance of a reliable market, cassava production can be increased.

The vision of the Pan African Cassava Initiative is '*Increased contribution of cassava as a food security crop and a major source of industrial raw materials for income generation in Africa by 2015'* (Boma, 2008). The transformation strategy will be an integrated business approach to providing technology to growers and linking farmers to markets with sustained support from the government and private sector (Boma, 2008). According to Kapinga *et al*. (1996) there has to be emphasis on the improvement of cassava genetic potentials so as to develop varieties with desirable acceptability, good resistance to pests and diseases and high root yield. This should go along with the strong commitment in multiplication of clean healthy planting materials of the released varieties and other potential local varieties. This can be achieved only if support to research can be increased both in terms of funds and human resources. Facilities for rapid propagation with Biotechnology could boost the efforts of multiplication (Kapinga *et al*., 1996).

The present policy emphasis is to expand production of domestic food crops for ensuring food security and export crops for increased earnings. As a result of this policy, there has been a shift towards cassava particularly in the drought prone areas because of the need for more drought tolerant crops (MALDC, 1995).

1.2 The Cassava Green Mite

Mononychellus tanajoa, a Neotropical Tetranychid mite pest of cassava also known as cassava green mite in English, *Acaro amarillo de la yucca* or *acaro verde de la yucca* in Spanish: *Acarien vertwas* in French and locally *Acaro verde da mandioca* in Brazil and *utitiri wa muhogo* in East Africa was accidentally introduced into Uganda (East frica) in the 1970s (Nyiira, 1972). *Manihot* is attacked by several pests, among which the cassava green mite is the most important (Moraes and Flechtmann, 2008). Similarly, pests and diseases cause considerable yield losses to cassava production. The most economically important pests are the cassava green mite, *Mononychellus tanajoa* and cassava mealybug, *Phenacoccus manihoti* while the most important diseases are the viral diseases, cassava mosaic disease (CMD) and cassava brown streak disease (CBSD) (Jeremiah *et al*., 2007). Therefore, *M. tanajoa* as a pest poses multi – dimensional problems and requires multi – dimensional solutions (Yaninek, 1994).

1.2.1 Taxonomy of *M. tanajoa*

Mononychellus tanajoa was first described in Brazil as *Tetranychus tanajoa* by Bondar (1938). *Tanajoa* is a Brazilian Indian word meaning disease of cassava. More so, Wainstein (1960) first proposed the genus *Monochychus* for species closely related to *tanajoa*. The species was later transferred to the genus *Mononychus* by Flechtmann and Baker (1970). Because of the prior usage of the name *Mononychus* for another group of animals, this group was newly named *Mononychellus* by Wainstein (1971). Nonetheless, Tuttle *et al.* (1977) have considered *M. tanajoa* to be a synonym of *M. caribbeanae* (MacGregor) while Doreste (1981) recognized *M. caribbeanae* as a distinct species and described *M. progressivus* and *M. manihoti* as new species found on cassava. However, it is currently agreed that until, and unless, distinct species can be demonstrated, the cassava green mite in Africa should be described as *M. tanajoa*. Similarly, there has been some confusion in the taxonomy of this species, it is now agreed that *M. tanajoa* and *M. progresivus* are one and the same species (Yaninek and Herren, 1988; Yaninek *et al.*, 1989; Bellotti *et al.*, 1999).

- Domain: Eukaryota
- Kingdom: Metazoa
- Phylum: Arthropoda
- Subphylum: Chelicerata
- Class: Arachnida
- Subclass: Acari
- Superorder: Acariformes
- Suborder: Prostigmata
- Family: Tetranychidae
- Genus: *Mononychellus*
- Species: *Mononychellus tanajoa*

Source: (ISC, 2015)

1.2.2 Host plants and spreading mechanism

Mononychellus tanajoa is found on cassava (*Manihot esculenta*) and other plants in the genus *Manihot*, such as *Manihot glaziovii* and *Manihot dichotoma* (Bastos and Flechtmann, 1985; Ezulike and Egwuatu, 1993a). However, Moraes *et al*. (1995) reported that cassava green mite could feed and develop to the adult stage on *Phaseolus vulgaris* and also develop to the adult stage and lay eggs on the wild passion fruit, *Passiflora cincinnata*.

Table 1.1: Some plants families attacked by Cassava green mite

Family	Plant Name	Context
Euphorbiaceae	*Manihot esculenta* (cassava)	Main
Fabaceae	*Phaseolus vulgaris* (Common bean)	Other
Solanaceae	*Solanum lycopersicum* (Tomato)	Main

Source: ISC (2015)

By 1985, the pest had spread throughout the cassava belt of Africa (Yaninek and Heren, 1988). Currently the pest is reported in over 60 countries including China (Lu *et al*., 2012). The pest is mainly dispersed by human activity whereby infested plant materials and contaminated media are transported to long distances. Natural dispersion by wind and water may also spread cassava green mites.

1.2.3 Biology of *Mononychellus tanajoa*

The biology of *M. tanajoa* including the developmental time, fecundity and adult longevity depends on temperature, humidity, host plant and the sex (Bryne *et al*., 1982b; Yaninek *et al*., 1989a. Yaninek *et al*., 1989a reported that at 27^{0C}, with relative humidity of 70% and a photoperiod of 12 hours light and 12 hours dark, the developmental time of egg, larvae, protonymph and deutonymph on leave of cassava (variety TMS 30572) were 5.4, 3.0, 1.1 and 2.8 days respectively. At this temperature, typical of most areas in sub – Saharan Africa, the adult female mite lives for 11.6 days and lays an average of 62.8 eggs over a period of 9.8 days. The net reproduction rate reached a maximum of 43.2 progeny, egg to adult developmental periods were estimated to be 21.3, 15.5, 12.3, 7.7 and 6.9 days at 20, 24, 27, 31 and 34^{0C} respectively. Reproduction of *M. tanajoa* is Arrhenotokous (a form of parthenogenesis whereby unfertilized eggs develop into males), with four active stages. *M. tanajoa*, like other members of the Acari, are recognized by their inconspicuous or absence of body segmentation giving the appearance of a single body unit. Cassava green mite also lacks wings, compound eyes and antennae. Adult females are bigger than the males and attain an average size of 0.8 mm (ISC, 2015).

Mononychellus tanajoa can feed and reproduce on other plants species (Moraes *et al*., 1995) and is reported as a quarantine pest (Delalibera *et al*., 1992; Eppo, 2009). The pest is biologically similar to other agronomically important Tetranychids (Huffaker *et al.*, 1970). The adult female lays fertilized female eggs and unfertilized male eggs. There are four active stages: i) a six-legged larva, two nymphal stages ii) Protonymph, iii) Deutonymph and iv) the adult stage. The protonymph is the first larval instar among the developmental stages of mites which is between eggs and deutonymph while deutonymph or hypopus is the second developmental instar of the mites, the two stages are feeding stages where they remain immobile. The eggs are tiny, spherical, pale-white, and are laid on the undersides of leaves often under the webbings. Eggs hatch in 4 or 5 days. Nymph looks similar to the adult but is only the size of an egg. It has only 6 legs. It molts 3 times before becoming an adult (Jewel, 2009). The adult is also very tiny, may be yellowish, greenish, pinkish, or reddish depending on the species. It looks like a tiny moving dot. It has an oval body with 8 legs and with 2 red eyes pots near the head of the body. The male is smaller than the female with a more pointed abdomen. A female usually has a large, dark blotch on each side with numerous bristles covering her legs and body (Jewel, 2009).

Generally, mites feed on the undersides of leaves. They use their sucking mouthparts to remove plant saps. The upper leaf surface has a speckled or mottled appearance while the underneath appears tan or yellow and has a crusty texture. Infested leaves may turn yellow, dry up, and drop in a few weeks. Mites produce large amount of webbing. Heavy infestation will result in a fine cobwebby appearance on the leaves. Plants die when infestation is severe (Jewel, 2009). The active stages prefer to feed on the terminal parts of the plant, killing leaf cells and reducing photosynthesis (Yaninek, 1994). Muaka-Toko and Leuschner (1980) found that oviposition of *M. tanajoa* increased at 28°C and greater hatching at 22°C, while the period of development (eggs/adult) was faster when the temperature increased from 22 to 35°C.

1.2.4 Geographical distribution and genetic variability of cassava green mites

In recent years, evaluation of genetic variability using nucleotide sequences of DNA has made it easier to characterize species diversity and has made it possible to determine the status of the taxa studied (Navajas *et al*., 1994). According to the previous finding, the detection and identification of DNA samples with PCR using specific primer pairs demonstrates that Brazilian and African isolates of (*Neozygites tanajoae*) *N. tanajoae* are genetically diverse. Although morphological similar can be separated by molecular techniques (Agboton *et al*., 2009a). Moreover, Inter – strain comparisons have shown that the two African mite populations appear to be identical. They were similar to the Colombian population while the Brazilian population was clearly different (Navajas *et al*., 1994).

Molecular markers have been used for monitoring the status of different mites dispersal in Benin, where the Brazilian isolates have been released to serve as an agent of biological control in 1999 (Bonaventure *et al*., 2009). In a study (Navajas *et al*., 1994), the sequences of the two DNA fragments analyzed indicated that the African species of cassava green mites from Benin and Congo are identical, suggesting that either the two groups shared a common ancestors in recent past or that they are bound by gene flow, but the letter hypothesis seems less plausible because of the geographical distance between Benin and Congo.

The distribution of *M. tanajoa* in Africa is like its primary host (cassava), it's originated from the Neotropics, where it occurs sporadically. Due to misidentification of the exotic mite, *M. progressivus* as *M. tanajoa*, in Africa, the distribution of *M. tanajoa* in this region requires careful scrutiny. The distribution data for *M. tanajoa* published from

1970s to the mid - 1990s during a time of taxonomic ambiguity may not be accurate as more current references (Hicks, 2017). However, as the pest was first introduced to Africa in Uganda where it was localized, the distribution started in 1972 and the mode of distribution was either wide spread, localized and present but no further details (Fig. 1.3).

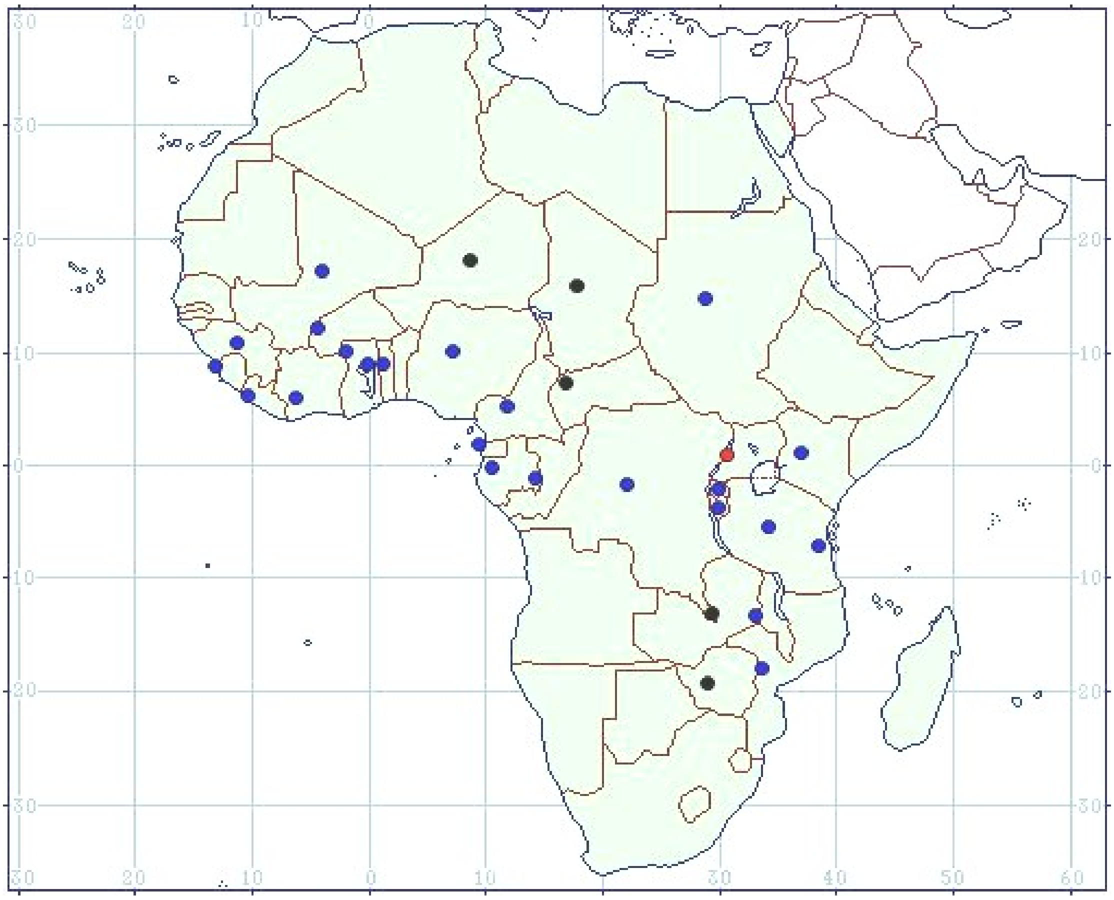

Figure1.3: Distribution Map of *Mononychellus tanajoa* in Africa

Source: Modified from SIC, 2016

Key = Wide spread Localized Present but no further details

1.2.5 Seasonality and population dynamics of *M. tanajoa*

Arthropods respond to seasonally unfavourable environmental conditions, mainly heat, cold, or drought, in various ways: Migration to an over seasoning habitat, dormancy ranging from quiescence to diapause, and acquired hardiness are three common adaptations that arthropods have developed to cope with temporarily adverse climatic conditions (Zundel *et al*., 2007). The densities of all developmental stages of *M. tanajoa* were low during the rainy season, increasing over the cassava cultivation cycle and reached its peak during the dry season (Evila *et al*., 2012). Mite infestation was greater in the driest season than in periods of high humidity in relation to other species that infest cassava, demonstrating that most damage of the crop occurred in the dry season (Yaninek *et al.,* 1989).

1.2.6 Effects of *M. tanajoa* on cassava varieties

Cassava green mite is the most important pest of cassava in many regions of the continent causing great yield losses estimated to be 30 – 80% (Yaninek, 1994). *Mononychellus tanajoa* attack mainly shoots and leaves of cassava reducing the photosynthetic rate and root dry matter (Moraes and Flechtmann, 2008). In Tanzania, cassava is attacked by various pests but the most important ones are cassava mealy bugs (*Phenacoccus manihoti,* Matile-Ferrero) and cassava green mites (*Mononychellus tanajoa* Bondar) (Legg and Raya, 1998).

Farmers in Africa grow several cassava varieties. For example, the COSCA researchers identified over 1000 local cassava varieties in six countries of the study, namely the Congo, Côte D’voire, Ghana, Nigeria, Tanzania and Uganda (COSCA Tanzania, 1996). In Tanzania most farmers especially in the Lake zone grow local cassava varieties despite the fact that the improved and high yielding varieties are available (Peter, 2011). The local varieties are preferred due to their prolonged underground root storage capacity and starchiness which suggests increased food security for households (Kulembeka *et al*., 1998; Nweke *et al*., 1998). However, the local varieties have inherent low yielding and late maturing characteristics and they are highly susceptible cassava green mite and diseases of cassava prevalent in the country (Peter, 2011). According to research done by Night *et al*. (2011), the cassava green mite population was found to be widespread in Rwanda, but the damage was mild. Moreover, the green mites were more severe on local varieties compared to improved varieties and damage was higher in the presence of adjacent cassava fields where there were local and improved cassava varieties. Where the occurrence of *T. aripo* on local cultivars was found high the number of green mite (based on severity of damage) was also found to be high on these cultivars.

In a study by Adebola *et al*. (2008) in Nigeria, the CGM damage assessment identified the varieties, MS 20, Antiota and Alice Local as the most resistant to CGM, whereas the most susceptible were Isunikankiyan, Amala, and TMS 30572 cassava varieties. Low severity and incidence of CGM and ACMD were recorded throughout the observation periods in high infection pressure area, such as Ibadan. This is a remarkable indication of promising levels of field resistance present in Cassava Landraces (Adebola *et al*., 2008).

1.2.7 Effects of seasons on *M. tanajoa*

Studies (Klein *et al*., 2002; Philpott *et al*., 2006; Teodoro *et al*., 2008) have indicated that Seasonal changes in diversity and density of arthropods in tropical regions have been attributed to temporal variation in local environmental factors such as temperature, rainfall and relative humidity. Spider mites are often positively influenced by temperature and negatively affected by rainfall (Bonato *et al*., 1995; Gotoh *et al*., 2004; Teodoro *et al*., 2008). *Mononychellus tanajoa* is the most serious pest worldwide, and has the widest distribution range because of its ability to tolerate harsh environmental conditions. More so, the Jackknife tests reveal that environmental variables associated with temperature have more influence on potential distributions of *M. tanajoa* than any other variable (Lu *et al.*, 2012). According to some reports, (Manu-Aduening *et al.*, 2007; Zundel *et al.*, 2009) temperature has a significant influence on the physiology of *M. tanajoa* population density. During the rainy season, the mites are substantially reduced as a result of rainfall washing off the colonies on leaves (Onzo *et al.*, 2005; Hanna *et al.*, 2005; Teodoro *et al.*, 2009a, b). Conversely, spider mites such as *M. tanajoa* build up larger populations during the dry season, which is characterized by high temperatures and low rainfall. More so, Teodoro *et al.* (2009a) have reported that the overall densities of eggs, adults and nymphs of *M. tanajoa* were higher than densities of larvae throughout the cultivation cycle of cassava, suggesting that each developmental stage of the cassava green mite experiences and respond uniquely to environmental factors operating at local scale.

Different researchers (Hanna *et al.*, 2005; Onzo *et al.*, 2005) have reported that seasonal population dynamics of *M. tanajoa* in the mid-altitudes of Cameroon turned out to be different from those in other African regions: i.e., from the lowlands of Benin, but also from the mid-altitudes of Kenya (Skovgard *et al.*, 1993) and Uganda. In these regions, Temperature is seen as a dominant factor for the *M. tanajoa* population growth rate. Annual average temperature in Benin is 25 to 27 °C and 23 to 24 °C in the mid-altitudes of Kenya.

Rainfall is the primary factor determining numbers of cassava green mites in the wet season (Yaninek *et al.*, 1987), and induced leaf abscission determines the green mite pattern in the dry season (Yaninek and Animashaun, 1987), but it is the nitrogen in leaves that determines the maximum *M. tanajoa* population growth rate. It has also been reported (Gutierrez *et al.*, 1988) that drought alone resulted in leaf abscission, and affected photosynthesis and yield, but the interactions were further compounded by green mite feeding.

1.2.8 Management of cassava green mite

1.2.8.1 Biological control of cassava green mite

Most recently studies with *Euseius citrifolius* Denmark and Muma and *Euseius concordis* Chant that are predatory mites of the family Phytoseiidae, commonly found in agro - ecosystems of cassava in South, Southeast and Center-West regions of Brazil. The results show the viability of the use of these organisms as biological control agents in cassava to control green mite (*Mononychellus tanajoa* Bondar), (Furtado, 1997).

The importation of phytoseiids from the neotropics (especially from Colombia and Brazil) and their release into Africa began in 1984 (ISC, 2016). In 1991, *Amblyseius* (=*Neoseiulus*) *idaeus* from north-eastern Brazil was reported to have persisted for over 18 months after release in Benin (Yaninek *et al*., 1991). In a study reported by Toko *et al*. (1996) the predator, *Amblyseius manihoti* was released into a cassava field infested with *M. tanajoa* at the beginning of the dry season and recorded a 20% decrease in the numbers of *M. tanajoa* compared with control areas where there were no predators. Moreover in Brazil, biological control, crop improvement and natural extracts are alternative control strategies of *M. tanajoa* (Andre *et al*., 2014). In areas where both the pest and host plant are exotic, there is no evidence that indigenous natural enemies are significant factors in limiting the mite population growth rates. Classical biological control aims at permanent control of a pest by the introduction and establishment of suitable natural enemies from the geographic origin of the pest for self-sustained maintenance of target pest populations below economically damaging levels (Eilenberg *et al*., 2001). Thus, because the pest (the cassava green mite) originates from the Neotropics, several explorations have been conducted there to select natural enemies in the area of origin of the pest and to introduce them into Africa in Benin and Cameroun.

A dozen of predatory mite species in the family Phytoseiidae have been selected in the Neotropics and shipped to Africa for experimental releases via the quarantine facilities at the University of Amsterdam (Yaninek *et al*., 1991). Among them, two are established in many parts of Africa: *Typhlodromalus manihoti* Moraes and *Typhlodromalus aripo* DeLeon (Yaninek and Hanna, 2003). Between these two exotic predator species, *T. aripo* is considered the most successful predator of cassava green mite due to its impact on the densities of the pest, its high capacity of dispersal and its persistence in cassava fields. Herrera *et al*. (1994) studied the population dynamics of *M. tanajoa* and its predators *Amblyseius limonicus* and *A. idaeus* on cassava at three sites in Colombia between 1988 and 1990. The numbers of the phytoseiids increased in response to the population growth of *M. tanajoa*, but higher predator densities were observed when *M. tanajoa* densities were low. At one site (Pivijay), *A. limonicus* appeared at the peak population of *M. tanajoa* and suppressed the pest population, while it persists during the wet season in the absence of *M. tanajoa*. Compared with plots without predators, cassava plots with predators harboured less than 50% of the *M. tanajoa* population and produced double the fresh tuber yields.

The mite, *Typhlodromalus manihoti* has been established in West Africa since its importation in 1989 from north-eastern Brazil which is ecologically more similar to sub-Saharan Africa than is Colombia (ISC, 2016). *Typhlodromalus aripo* was introduced from Brazil into West Africa to control *M. tanajoa* in 1993 (IITA, 1996). The predator has now spread at same instances at a rate of 200 km/year, and established itself in more than 11 countries in Africa. The population *M. tanajoa* have subsequently dropped to less than 20/leaf, from more than 40/leaf before the introduction of *T. aripo*. Post release surveys conducted under farm field conditions in Tanzania reported a decline of *M. tanajoa* population densities from >200 mites per leaf (before *T. aripo* introduction) to <20 mites per leaf (Pallangyo *et al*., 2004). During a predator exclusion experiment, *M. tanajoa* population densities and damage severity were reduced by 64.3% and 45.3% respectively leading to an increase in cassava yield by up to 70%. In Benin, this has led to a 30% increase in tuber yields, equivalent to a gain of $3 million per season (Pallangyo *et al*., 2004). The predatory insects *Stethorus spp*. and *Holobus* (= *Oligota*) *spp*. have also been reared and released in a number of countries (ISC, 2016). Among the fungal pathogens, *Neozygites spp*. has shown the greatest potential for biological control. It has been reported to cause mortalities among *M. tanajoa* populations in Venezuela (Agudelo-Silva, 1986), Brazil (Delalibera *et al*., 1992), Colombia (Alvarez *et al*., 1993), Benin (Yaninek *et al*., 1996) and Kenya (Bartowski *et al*., 1988). The effect of abiotic factors on the ability of this fungus to cause epizootics among populations of *M. tanajoa* has been studied by Oduor *et al*. (1995a, b; 1996a, b; 1997a, b). Brazilian species are being compared with African strains to identify the ideal isolate for mass release in Africa. A study (Andre *et al*., 2014) showed that there exists practical difficulties to completely substitute the chemical methods; however the integration of biological methods can be used to increase cassava production in Brazil without the use of pesticides and with the use of integrated pest management-IPM.

1.2.8.2 Chemical control of cassava green mite

The use of chemicals is not common among farmers especially in sub–Saharan Africa and most cassava is grown on a small scale by subsistence farmers with few resources (ISC, 2016). Lack of knowledge and finance makes the use of chemicals a non-sustainable option for controlling *M. tanajoa*. Pesticide resistance is also a problem in the long term (ISC, 2016; Plantwise, 2016). The use of chemicals by smallholders is often not possible due to the cost. Furthermore, pesticides reduce the population of natural enemies which can cause the mite populations to increase rapidly (Plantwise, 2018). When *M. tanajoa* was discovered in Uganda, several chemicals were screened as possible acaricides (Nyiira, 1972), but chemical control was then (Nyiira, 1976; Yaninek and Herren, 1988) continue to be beyond the economic means of most farmers in Africa. Chemical treatments, although effective in the short term, usually caused secondary pest outbreaks, and posed a threat of pest resurgence due to rapidly induced pesticide resistance in the long term (Nyiira, 1976; Yaseen, 1977).

1.2.8.3 Other control methods of cassava green mite

Regulatory control is normally carried out with close inspection of cutting materials and the use of clean certified cuttings and this may reduce the spread of *M. tanajoa* and delay the time of infestation of the cassava crop (ISC, 2015). Cultural control is limited owing to economic, technical and social constraints. Options include early planting at the onset of the rains to encourage vigorous growth and thereby increase tolerance to mite attack. Cassava plants aged 2-9 months are the most vulnerable to infestation (ISC, 2016).

1.2.8.4 Host-plant resistance of cassava green mite

Certain attributes, such as leaf pubescence (Leuschner, 1982), have been claimed to confer tolerance to *M. tanajoa*. Some attempts have been made to identify mite-resistant cassava cultivars (Shukla, 1976; Santos *et al.*, 1977; Byrne *et al.*, 1982a, b; Markham and Robertson, 1987; Msabaha, 1984) but further studies including damage symptoms, tuber yields and disease resistance of the selected cultivars need to be carried out, moreover, the immunity to *M. tanajoa* is not known. In Brazil, crop improvement is alternatively used to control of *M. tanajoa* in the country (Andre *et al.*, 2014).

1.3 Justification of the Study

The green mite, *M. tanajoa* is widely distributed but is more devastating across the Lake zone and can cause 60% to 80% crop loss if left uncontrolled (Anon, 1999). More so, it was the most widely spread among the pests and diseases observed in more than 90 percent of the representative villages (COSCA Tanzania, 1996). The varied magnitude of damage caused by *M. tanajoa* in Lake Zone is quite higher than other parts of the country suggesting differences in the environmental variables across the major cassava producing zones in the country.

In Tanzania, cassava is an integral component of most cropping systems and is among the most important staples in many zones. It plays an important role as a food security crop and provides useful opportunities for extending labour use and exploiting price peaks in the food market (Kapinga *et al*., 1996). It is an essential component of the subsistence food crops in the semi-arid areas and sometimes considered as a famine reserve when cereals fail due to its drought tolerance and the fact that the roots can readily be stored underground (DRT, 1991). Recent erratic changes due to global warming culminating into failure of grain crops have stimulated farmers in the semi-arid areas to increase attention to the potential of cassava to mitigate effects of famine (Nweke *et al*., 1998; Spittel and Van Huis, 2000).

Furthermore, cassava is progressively shifting from being a staple food for humans and livestock into an efficient industrial crop, particularly in the developing countries around Asia, Latin America and Africa (Baguma and Kawuski, 2006). It is currently an important source of starch for the textile industries in Tanzania and other parts of the world. This has made cassava an important food and cash crop in Tanzania especially the

Lake zone where it is extensively grown (Nweke *et al*., 1998; Kapinga *et al*., 2005). The potential also exists for the production of sugars, alcohol, esters, ketones, ethers and many organic chemicals and compounds from cassava that are used in the chemicals, pharmaceuticals, textiles, metallurgical, veterinary and fishery industries (Rongjun, 2000). Advances in cassava processing into starch, baking flour, alcohol and animal feeds have also made it to be a very important cash crop in the cassava producing zones of Tanzania. This has made farmers in Tanzania especially in the Coast and Lake Zones to rate cassava as their most preferred cash crop (Spittle and Van Huis, 2000).

Despite its importance and diverse use, cassava production in Tanzania (5.6 million metric tons) is grossly low while Nigeria and Angola (57.1 and 9.9 million metric tons respectively) compared to world production statistics (277.1) million metric tons) (FAOSTAT, 2016). Several efforts have been made since mid-1980s by the Tanzanian national root crop research program and international organizations particularly the International Institute of Tropical Agriculture (IITA) to breed for new varieties with acceptable agronomic qualities mainly yield. Such efforts have greatly addressed disease problems (cassava mosaic disease and cassava brown streak virus disease) although production has not improved to great extent. As such many other biotic and abiotic production constraints remains to be addressed among which Cassava green mite, *Mononychellus tanajoa* is important. Cassava consumption in Tanzania is gaining popularity and the high demand cannot be met with current production level (Nweke *et al*., 1998).

Several improved commercial cassava varieties have been bred and officially released in Tanzania especially in 2010, but limited information exists on their response to *M. tanajoa*. Researches geared at understanding the ecology and the importance of this pest is scarce. The dynamics of the pest population in major cassava producing zones of Tanzania is not known. Moreover, the damage impact of the pest in Tanzania has never been explored. There were reports on the presence of the pest in only one zone, but no further details of comparison from other zones. The environmental factors were reported to influence the pest's dynamics and damage without any valid researchable reasons across the zones and cassava growing seasons. There have been concerns on how can the recently released cassava varieties responds to cassava green mite's damage. Mites have received less attention over years (Yaninek, 1994) due to over concentration on viral diseases. The study aimed to generate key information for successful CGM management in Tanzania and elsewhere. Therefore, the outcomes are of significant importance in designing strategies to manage the pest and subsequently minimize the associated losses in Tanzania and elsewhere on cassava crop.

1.4 Objectives of the study

1.4.1 Overall objective

To establish the pest status of cassava green mite and examine factors influencing its dynamics for ease of management.

1.4.2 Specific objectives

The specific objectives were:

i. To determine the spatial distribution of *Mononychellus tanajoa* on commonly grown cassava varieties in the Eastern, Lake and Southern zones of Tanzania.

ii. To evaluate the environmental influence on occurrence and perpetuation of *M. tanajoa* on selected cassava varieties.

iii. To assess the abundance of *M. tanajoa* and associated damages on commercial and popular cassava varieties in the Lake zone.

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CHAPTER TWO

2.0 SPATIAL AND TEMPORAL DISTRIBUTION OF CASSAVA GREEN MITE, *Mononychellus tanajoa* Bonder (Acarina: Tetranychidae) IN TANZANIA

2.1 Abstract

Cassava green mite, *Mononychellus tanajoa* Bonder, causes serious cassava root yield reductions in the dry savanna regions of Africa. The pest was first reported in Tanzania in early 1970s and continues to cause losses on cassava. Two diagnostic surveys were conducted during 2015 and 2016 in three major cassava growing zones of Tanzania. The studies aimed at establishing the spatial and temporal distribution of *M. tanajoa* on commonly grown cassava varieties during the 2015 and 2016 dry seasons in Tanzania. A total of 5400 plants in 180 fields were assessed in nine districts of which five districts were in the Lake zone and two in each of the Southern and Eastern zones in both years. Thirty (30) cassava plants/farm were randomly sampled along the diagonals and the mites were physically counted by inspecting the upper most 5 leaves using a hand lens (Model No. YT1045/50mm). Other data collected were the age of the plant, type of cassava variety planted, cropping system and the Coordinates (Latitude, Longitude and Altitude). These were taken using Geographic positioning System (GPS) (Germin International Cooperation, 2013). The maps were drawn using the ArcView Esri software (Environmental Systems Research Institute). The results indicated that the distribution of *M. tanajoa* significantly ($P \leq 0.05$) differed across years, Lake zone (1.609, 1.530), Southern zone (1.619, 1.19) and eastern zone (1.253, 0.90) in 2015 and 2016 respectively. The Southern and Lake zones were statistically similar and higher in *M. tanajoa* population than the Eastern zone. The crop age (<6 = 2.028, <9 = 1.427, <12 = 1.678 and >12 = 1.602), altitude (0 – 300 = 1.658, 301 – 800 = 1.352 and >800 = 1.609) and cassava varieties (Kachaga = 2.360, Lufaili = 2.150, and Liongo Kwimba = 1.100) significantly ($P \leq 0.05$) influenced the population of *M. tanajoa* while cropping systems had no significant effect in both 2015 and 2016. The relationship among the environmental variables (rainfall, temperature and relative humidity) and population distribution of *M. tanajoa* were significant ($P \leq 0.05$). The survival, perpetuation and distribution of *M. tanajoa* were attributed to the differences in varietal responses and preference, crop age and weather variables.

Key words: Cassava Green Mite, Spatial, Temporal, Distribution, Cassava varieties, Tanzania.

2.2 Introduction

Cassava green mite, *Mononychellus tanajoa* is among the most serious pest worldwide (Lu *et al*., 2012), and has the widest distribution range because of its ability to tolerate harsh environmental conditions. The Jackknife tests reveal that environmental variables associated with temperature have more influence on the distribution of *M. tanajoa* than any other variable (Lu *et al*., 2012). According to some reports, (Onzo *et al*., 2005; Hanna *et al*., 2005; Manu-Aduening *et al*., 2007; Zundel *et al*., 2007; Teodoro *et al*., 2009a, b) during the rainy season, the mites are substantially reduced as a result of rainfall washing off the colonies on leaves. Conversely, *M. tanajoa* build up in larger populations during the dry season, which is characterized by high temperatures and low rainfall. Teodoro *et al*. (2009a) reported that the overall densities of eggs, adults and nymphs of *M. tanajoa* were higher than densities of six legged throughout the cultivation cycle of cassava, suggesting that each developmental stage of the cassava green mite experiences and respond uniquely to environmental factors operating at local scale.

Cassava is attacked by various pests but the most important ones in Tanzania are cassava mealy bug (*Phenacoccus manihoti,* Matile-Ferrero) and cassava green mites (*Mononychellus tanajoa* Bondar) (Legg and Raya, 1998). Despite its economic importance and diverse use, cassava production in Tanzania (5.6 million metric tons) is grossly low and the harvested area 1061043ha while Nigeria and Angola (57.1 and 9.9 million metric tons respectively) compared to world production statistics (277.1 million metric tons). Therefore, cassava productivity in the country is also low (5.236 t/ha) (FAOSTAT, 2016). Several efforts have been made since mid-1980s by the Tanzanian national root crop research program and international organizations particularly the

International Institute of Tropical Agriculture (IITA) to breed for new varieties with acceptable agronomic qualities mainly yield. Such efforts have greatly addressed disease problems (cassava mosaic disease and cassava brown streak virus disease) although production has not improved to great extent. As such many other biotic and abiotic production constraints remain to be addressed among which Cassava green mite, *Mononychellus tanajoa* is important. The current study aimed at establishing the spatial and temporal distribution of *M. tanajoa* in Tanzania. The outcome(s) could be useful in designing strategies to manage the pest to minimum damage threshold level and subsequent losses in Tanzania.

2.3 Materials and Methods

Two diagnostic surveys were conducted on farmers' fields during 2015 and 2016 in the Lake, Southern and Eastern Zones of Tanzania. The timing was during the dry season in July, the period characterized by conditions that favour mites' perpetuation. Surveyed areas were; five districts in the Lake Zone (Sengerema, Misungwi, Kwimba, Bunda and Ukerewe Island), two districts in the Southern Zone (Mtwara rural and Mtwara Municipal) and two others in the Eastern Zone (Kibaha and Mkuranga) making a total of nine districts. In each district, ten farmers' fields were randomly selected and the sampling distance interval was at least 4km along passable roads. A total of 5400 plants were assessed in 180 farmlands in both years. In each farm, thirty (30) cassava plants were diagonally selected and assessed leaving at least two boarder rows to avoid the edge effects (Evila *et al*., 2012). A total of 5400 plants were assessed for *M. tanajoa* during each of the two surveys.

Weather data on temperatures, rainfall and relative humidity were collected from the Tanzania meteorological stations of the respective zones (Appendix 2.2). The influence of weather parameters on occurrence and perpetuation of *M. tanajoa* was analyzed through multiple regressions. The predicted influence of the weather parameters on the pest count was assessed based one month before and during the actual survey in the three zones in 2015 and 2016.

2.3.1 Assessment of the *Mononychellus tanajoa* population

The population of *M. tanajoa* was assessed once (during the dry season i.e July) in each of the two years by inspecting the 5 upper most leaves on the abaxial parts and the mites were manually counted, aided by hand lens (Model No. YT1045/50mm) and the numbers recorded in the survey field note book. Other data collected were the coordinates (Latitude, Longitude and Altitude) of each surveyed farm using the Geographic Positioning System (GPS) (Oregon 450, Germin International Co-operations), the crop age, cassava variety grown, the cropping system (Inter cropped or mono cropped) and the biotic stresses such as viral diseases including Cassava Mosaic Disease and Cassava Brown Streak Disease.

2.3.2 Statistical analysis

All collected data were subjected to non-parametric (K-Independent samples) analyses in SPSS version 16.0, (SPSS Inc., 2011) and Kruskal-Wallis test was used to establish comparisons among population of *M. tanajoa.* Multiple regression analysis was carried out to predict the relationship between weather variables and *M. tanajoa* population and damages.

2.4 Results

The obtained results from surveys suggested that inter annual variation in *M. tanajoa* population was significant ($P \leq 0.05$) in both years (2015 and 2016 dry seasons) (Table 2.1). The *M. tanajoa* counts in 2015 were significantly ($P \leq 0.05$) higher compared to that of the 2016 season. Moreover, the difference among *M. tanajoa* population was highly significant ($P \leq 0.001$) between the Eastern zone and the rest of the zones in both years. Highest number of *M. tanajoa* was recorded in the Southern and the Lake zones (0.0854 and 0.0701 in 2015 and 1.53 and 1.19 in 2016 respectively). Despite the general reduction in the number of *M. tanajoa* across the zones in 2016, the Lake zone remained statistically similar to the Southern zone (Table 2.1).

Table 2. 1: **Counts of *Mononychellus tanajoa* (mean $\pm$ SD) in three different zones of Tanzania**

Zones	Counts/Leaf (2015)	Counts/Leaf (2016)
Lake Zone	1.609 ± 0.635^{a}	1.527 ± 0.686^{a}
Southern Zone	1.619 ± 0.314^{a}	1.190 ± 0.312^{a}
Eastern Zone	1.253 ± 0.388^{b}	0.895 ± 0.293^{b}
P value	**0.002**	**0.000**

A comparative analysis of *M. tanajoa* population among districts indicated that Kwimba and Misungwi districts of the Lake zone recorded the highest population compared to all other zones in the country across the 2 years (Figure 2.1). Contrary to what was expected particularly for Ukerewe Island, the district recorded minimal (0 – 10 mites/leaf) to moderate (11 – 20 mites/leaf) number of the pest despite the fact that the first record of *M. tanajoa* in Tanzania was in the Island. Similar to Ukerewe Island, the neighbouring district, Bunda in the Lake zone also recorded low mites' numbers (0 – 10 mites/leaf) in 2015 and were moderate in 2016.

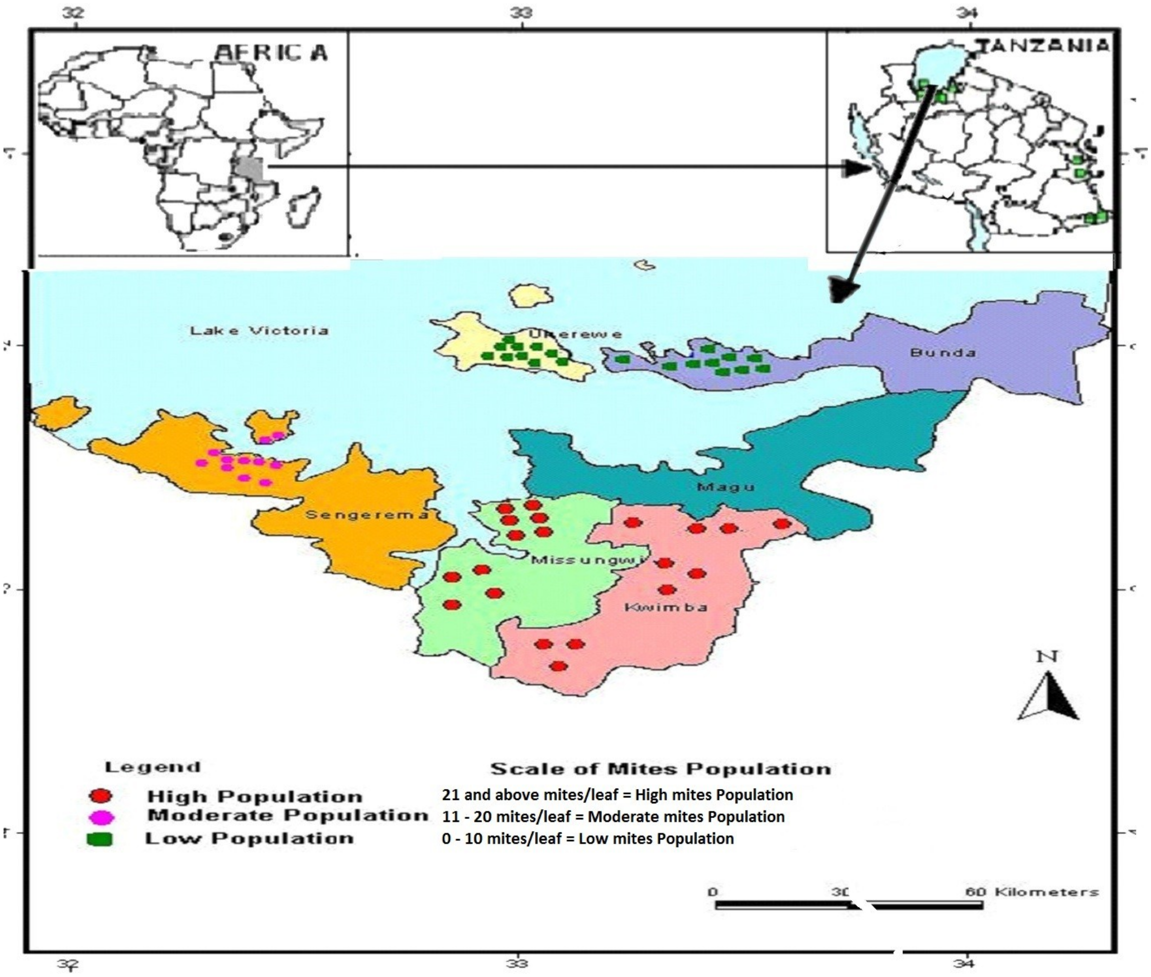

Figure 2.1: Population distribution of *M. tanajoa* in the Lake Zone, Tanzania

The Southern Zone districts recorded high *M. tanajoa* counts and was significant (P≤0.001) where Mtwara rural district recorded a higher (21 and mites/leaf) counts of *M. tanajoa* in 2015 and it was moderate (11 – 20 mites/leaf) in 2016 while Mtwara Municipal had moderate mites' counts in both years (Fig. 2.2).

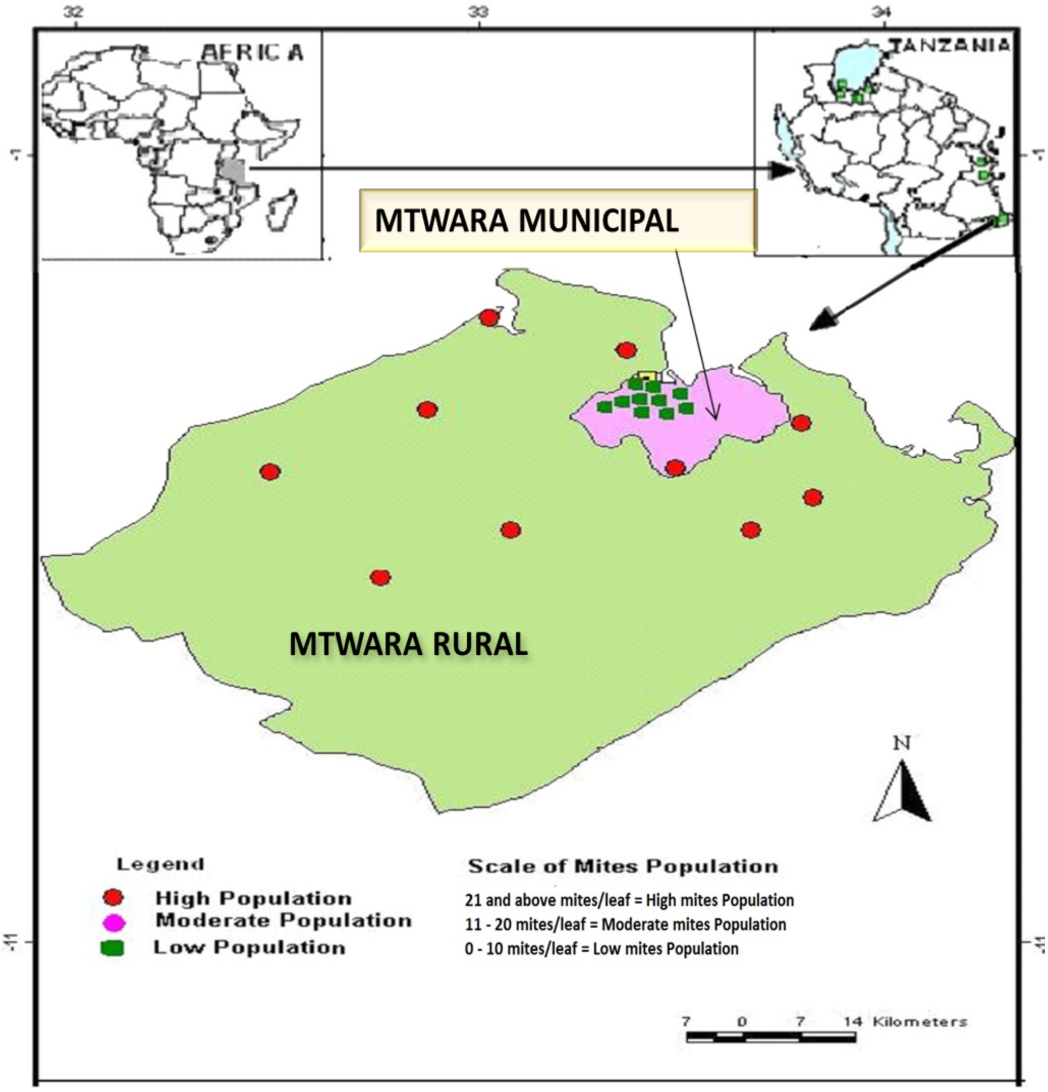

Figure 2.2: Population distribution of *M. tanajoa* in the Southern Zone, Tanzania

The result indicated that the Eastern zone (Coast) recorded the lowest (0 – 10 mites/leaf) *M. tanajoa* counts among the three zones in both years (Fig. 3.3). Generally, higher counts were significantly ($P \leq 0.05$) recorded in 2016 compared to 2015 (Table 2.2). Varied influence of crop age on *M. tanajoa* was observed during the two years (2015 and 2016).

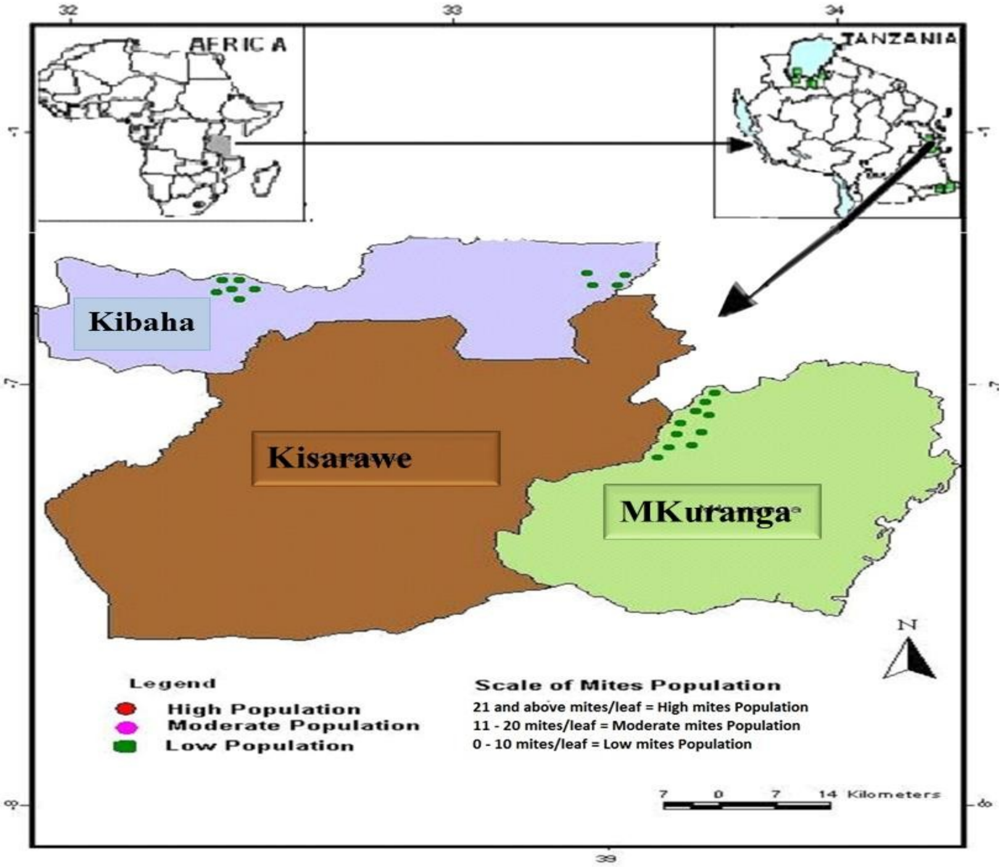

Figure 2.3: Population distribution of *M. tanajoa* in the Eastern Zone, Tanzania

The age of cassava (at <6 months) crop significantly (P≤0.001) affected *M. tanajoa* counts in the three agro-ecological zones in both years (2016 and 2015) (Table 2.2). Analysis of the crop age influence in each year indicated that cassava plants below six months of age (<6 months) recorded higher counts of *M. tanajoa* followed by those aged above 12 months in 2015. The least counts of *M. tanajoa* were recorded on cassava plants of less than 9 months but older than 6 months.

Altitude had significant impact on *M. tanajoa* counts (P≤0.05) throughout the three agro-ecological zones (Table 2.2). In the Southern zone (Low altitude, 0 - 100m asl) along the coast significantly (P≤0.05) recorded the high counts of *M. tanajoa* in 2015. Similarly, the high altitude (>500m asl) in the Lake zone recorded high mites' counts than the

Eastern zone. However, the variation trend was similar but generally minimal in 2016. The intermediate altitude (101 - 500m asl) in the Eastern zone (coastal region) recorded the least *M. tanajoa* counts (Table 2.2).

Table 2.2: Effects of crop age and Altitude on the counts of *Mononychellus tanajoa* (mean ± SD) in Tanzania

Crop Age (Months)	Counts/Leaf (2015)	Counts/Leaf (2016)
<6	2.0280 ± 0.80751	2.176 ± 0.803
<9	1.4265 ± 0.48507	1.188 ± 0.548
<12	1.4265 ± 0.48507	1.428 ± 0.688
12 and Above	1.6064 ±0 .046782	1.476 ±0 .494
P value	**0.069**	**0.003**
Altitude		
0 - 100	1.6582 ± 0.35938	1.346 ± 0.357
101 – 500	1.3517 ± 0.37879	1.017 ± 0.340
>500	1.6092± 0.60354	1.527± 0.686
P value	**0.039**	**0.001**

The *M. tanajoa* counts on cassava varieties was highly significant (P≤0.001) in both 2015 and 2016 (Fig. 2.4). The cassava varieties assessed had varied *M. tanajoa* counts, suggesting that population build up and subsequent distribution of the pests is influenced by the characteristics of the respective cassava varieties. In both years, cassava varieties Lufaili, Ismaili, Kachaga and Kuchangoma recorded the highest counts of the pest; others are Kuchangoma and Liongo Kwimba and are all the local varieties from the Lake zone (Fig. 2.4). The least infested varieties were Zagazaga, Rasta, Kalingisi and Kiroba in which Kiroba is an improved variety.

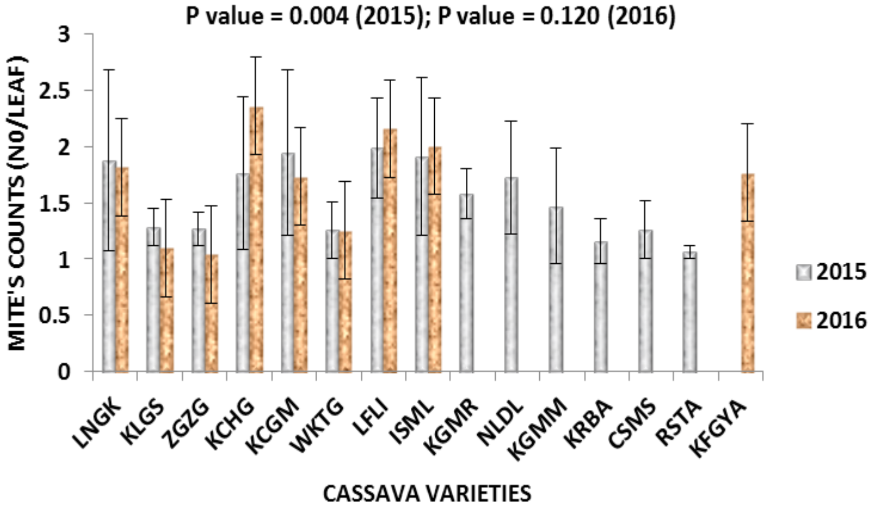

Figure 2.4: Effects of cassava varieties on the counts of *Mononychellus tanajoa* in Tanzania

The effect of cropping systems on the counts of *M. tanajoa* suggested no difference between the sole crop and intercropped plantings in both 2015 and 2016 (Figure 2.5). However, the comparative assessment of the influence of crops intercropped with cassava showed that soybeans + cassava mixture recorded the highest number of *M. tanajoa* followed by sorghum + cassava mixture. The lowest *M. tanajoa* count was recorded in sweet potato + cassava mixture followed by cowpea + cassava and cashew + cassava respectively.

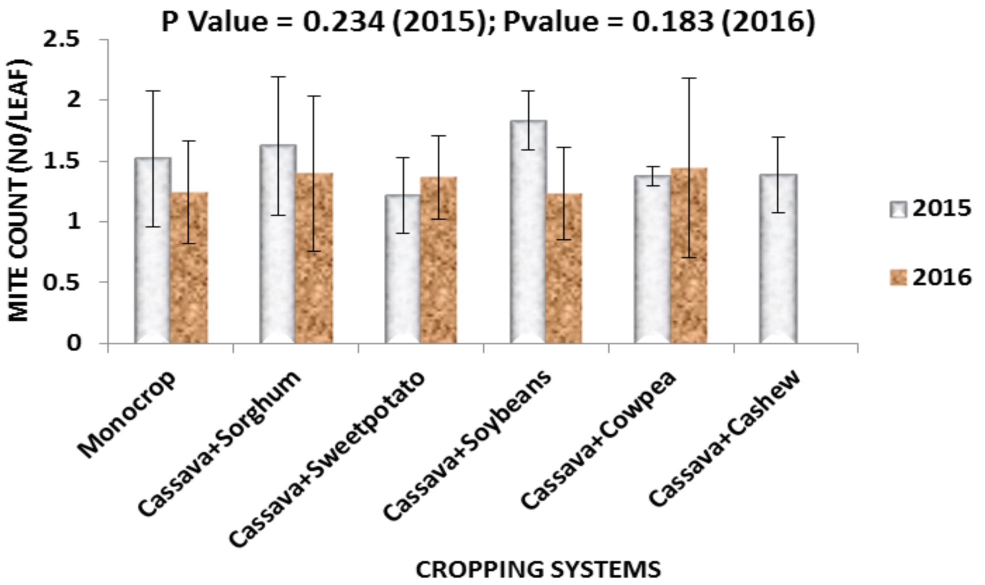

Figure 2.5: Effects of cropping systems on the counts of *M. tanajoa* in Tanzania

The percentage contribution of each of the dependent variables to the counts and distribution of *M. tanajoa* was also determined. The overall variance on mites' counts during the data collection in July, 2015 as explained by the three predictors was 8.1%. All tested predictors, rainfall (β = -0.406, p≤0.0.007), maximum temperature (β = -14.35, p≤0.010) and relative humidity (β = -0.0054, p≤0.524) were significant and negatively related to *M. tanajoa* counts. However, in July 2016, only rainfall (β = -0.1091, p≤0.001) was significant and negatively correlated to *M. tanajoa* (Table 2.3).

Moreover, one month before data collection (June, 2015), rainfall (β = -0.0382, p≤ 0.180) was negatively related and relative humidity (β = 0.0263, p≤ 0.914) positively related to *M. tanajoa* counts although the two were not significant however, temperature (β = 7.77, p≤ 0.011) was significant and positively related. The established overall variance between the predictors and the number of mites before data collection in (June) 2016 was 17.7%. It was predicted (in June 2016), that all the weather variables rainfall (β = -0.2109, p≤0.001), temperature (β = -0.674, p≤0.001) and relative humidity (β = -0.1432, p≤0.076) were significant and had negatively affected *M. tanajoa* counts in 2016 (Table 2.3).

Table 2.3: Regression analysis of some weather variables against *M. tanajoa* at the time of survey and one month before survey in Tanzania

July 2015 Counts/Leaf				**July 2016 Counts/Leaf**		
Parameter	**Beta (β Value)**	**SE±**	P value	**Beta (β Value)**	**SE±**	P value
Rainfall	-0.406	0.147	0.007	-0.1091	0.0265	0.001
Temperature	-14.35	5.47	0.010	0.251	0.188	0.185
Relative humidity	-0.0054	0.0502	0.524	0.0621	0.0448	0.169
June 2015 Counts/Leaf				**June 2016 Counts/Leaf**		
Rainfall	-0.0382	0.0283	0.180	-0.2109	0.0530	0.001
Temperature	7.77	2.98	0.011	-0.674	0.157	0.001
Relative humidity	0.0263	0.0410	0.914	-0.1432	0.0797	0.076

Figures in parentheses are P values (significant at * ≤ 0.005, ** ≤ 0.001)

2.5 Discussion

Drier conditions especially in July might have encouraged the survival, perpetuation and distribution of *M. tanajoa* in the two zones (Lake and Southern zones), similar observations were reported by Hanna *et al*. (2005) and Onzo *et al*. (2005). The higher rainfall observed in the Eastern zone in both years had led to the low mites compared to the Lake and Southern zones. Moreover, differences in counts of *M. tanajoa* among the zones (Table 2.1) might also be due to the different inherent characteristics of the planted cassava varieties that triggers varied responses to the pest, similar findings were reported by Barbar *et al*. (2006). The higher *M. tanajoa* in 2015 compared to 2016 (Table 2.1) could be attributed to higher relative humidity experienced one month before data collection in 2015. The low rainfall could have influenced the growth, development and perpetuation of the mites compared to 2016.

Conversely, in 2016 low *M. tanajoa* counts were observed especially in Lake and Southern zones, suggesting the impacts of higher rainfall on the pest. Moreover, rainfall exerted its kinetic energy that struck on *M. tanajoa* washing off the mites from cassava shoots and killing the pest, similar observation was reported by Yaninek *et al*. (1987).

Nonetheless, water droplets that drown and kill mites and low temperatures might have all trigger delayed growth and development of *M. tanajoa* contributing to the low mite counts during the rainy season (Yaninek *et al*., 1987). Limited availability of fresh plant growth (during the main part of the dry season) and occasional rainfall in between July and September could be among factors that kept the pest counts low as was similarly observed by other workers (Yaninek *et al*., 1989a;1989b; Hanna *et al*., 2005 and Onzo *et al*., 2005).

Mononychellus tanajoa has been reported to prefer young, tender and succulent parts (table 2.2) of the cassava plant as they are more nutritious (Nitrogen rich) attracting higher mite density (Yaninek *et al*., 1987). Colonization and concentration of *M. tanajoa* on the apical parts of the cassava plant has been reported (Evila *et al*., 2012, Yaninek *et al*., 1987; 1989). Similar observations showed that cassava plants aged 2-9 months are the most vulnerable to mites' infestation (ISC, 2016). However, older plant leaves (<12 months and above) are of inferior nutritive value (e.g. low nitrogen) thus they habours low mite counts. Some contrasting results however were reported in Kenya (Mutisya *et al*., 2015) that crop age was associated with severe mite distribution in older plants. Studies in Rwanda reported a widespread distribution of *M. tanajoa* (Night *et al*., 2011) suggesting a limited impact of weather factors on mites counts.

The higher counts were recorded in the low altitude area (the least 6m asl) followed by the high altitude area (above 1000 m asl) indicated that environmental factors (especially temperature, rainfall and relative humidity) played a more vital role than the altitude on the perpetuation of *M. tanajoa* in the two zones as they share similar pattern of seasons especially in rainfall and temperature regimes (Table 2.2).

Generally, most of the cassava varieties responded differently to *M. tanajoa* damage and influenced the pest's dynamics across the zones and years (Figure 2.4). The differences in mites' density in the two years might not only be attributed to variation in weather factors but also the inherent genetic traits of the grown cassava varieties which in turn affected preferences by the *M. tanajoa* (Nukenine *et al*., 1999). The inherent characteristics may lead to some varieties being resistant while others susceptible to *M. tanajoa*. Available reports suggest that the resistant cassava varieties tend to have high leaf pubescence (Paters and Berry, 1980) and high canopy retention ability during the dry season (Nukenine *et al*., 1999). Such particular characteristics were apparent in Kiroba (a variety grown in the Eastern zone) and Lwakitangaza, Kuchangoma and Kalingisi (Lake zone) while Cosmos and Kigoma red (Southern zone) were mildly attacked varieties. Nonetheless, other defense mechanisms by the host plants have been reported to bring about variation in cassava response to *M. tanajoa.* Non-preference and antibiosis are among common mechanisms on the leaves of the resistant genotypes (Nukenine, 2002). According to Yaninek and Hanna (2003) and Gnanvossou *et al*. (2005), *T. aripo* is able to survive and develop also on alternative food, such as cassava extra floral exudates, and maize pollen therefore, might predate on *M. tanajoa* at later time of the data collection thus, would help to reduce *M. tanajoa* counts in later stage. Available production data indicates that the cassava variety Kiroba is the dominantly cultivated by farmers in the Eastern zone and is said to be moderately resistant to *M. tanajoa*, whereas Liongo Kwimba variety is the predominantly cultivated in the Lake Zone and is highly susceptible to *M. tanajoa* attack (Nukenine *et al*., 2002).

Cassava inter crop with other crops had no significant effect on the counts of the cassava green mite (Fig. 2.5), and this corroborates the work of (Toko *et al*., 1996), who reported that intercropping cassava with maize had no significant effect on *M. tanajoa* and associated phytoseiid predator populations during the intercropping dry, and post dry seasons, however this is in contrast with the findings of Mutisya *et al*. (2015) that the intercropping was associated with reduced frequency of high damage severity scores. More so, Ezulike and Egwuatu (1993a) reported that cassava intercropped with pigeon pea suffered less damage from *M. tanajoa* than that grown on a pure stand. They further found that cassava intercropped with pigeon pea in triple and double rows gave higher tuber yields than when it was alternated in a single row or in a pure stand. The effect of intercrop on *M. tanajoa* counts could be more related to the crop with which cassava is intercropped. Therefore, the distinction between the two years (2015 and 2016) could generally be linked to the number and types of cassava varieties and the environmental variables found during the periods of the surveys. The counts' trends in both years were quite similar with a slight difference in numbers which fluctuate among crop types. This could also be due to the differences in the weather variables among the zones and within and between the years. Furthermore, the variations in mite counts between the two experimental years (2015 and 2016), might be due to the fact that different cassava varieties were used and the sites were located in different places and thus the differences occurred between the two years. This has been reported by other researchers (Evila *et al*., 2012 and Zundel *et al*., 2007).

The Lake and Southern zones have similar pattern and durations of dry season, the most conducive environmental conditions for the survival and perpetuation of *M. tanajoa* explaining the reasons for similarities in *M. tanajoa* counts and distribution. The dry season normally starts in late May and ends in November in the Lake Zone and April to September or October in the Southern zone. On the other hand, the Eastern zone has a bimodal pattern of rainfall where the dry season starts in July or late June sometimes with showers in between the months. Therefore, the environmental variables especially rainfall, temperature and relative humidity might sometimes differ based on zones, especially Lake and Eastern zone. These factors might have probably dictated for the differences in the survival and perpetuation of the mites among the zones. The influence of seasonal changes in temperature, rainfall and relative humidity on diversity and density of arthropods in the tropical regions have previously been reported (Klein *et al*., 2002; Philpott *et al*., 2006; Teodoro *et al*., 2008). Several researchers have reported that spider mites are often positively influenced by temperature and negatively affected by rainfall. The effect of environmental factors such as temperature, relative humidity and rainfall being important factors influencing the population dynamics of arthropods in agro-ecosystems has been broadly reported (Prischmann *et al*., 2005; Barbar *et al*., 2006; Teodoro *et al*., 2008). Similarly, the influence of temperature on *M. tanajoa* development was exacted through a research in Kenya and Benin that due to the low average temperature (21 °C in the mid-altitudes; 23 °C in the lower altitudes) mites development was very slow (Evila *et al*., 2012). It takes a population 1.8 times longer to double its number at 20 °C than at 24 °C, and 2.6 times longer than at 27 °C. Negative correlations between rainfall and the developmental stages of *M. tanajoa* have been reported (Bonato *et al*., 1995; Gotoh *et al*., 2004; Teodoro *et al*., 2008) suggesting that the counts of *M. tanajoa* decreases with increasing rainfall and this could be related to the Lake and Southern Zones' high density of the pest. Other similarities that exist between Lake and Southern zones could also be attributed to the higher intensity of cassava cultivation in the two zones. The two have been reported the leading cassava producing zones in the country (TZNY, 2012). The intensive cassava production and favourable weather (temperature and rainfall) ensures cumulative population build–up over time continuously on the preferred host, the cassava.

2.6 Conclusion

The study revealed that *M. tanajoa* counts were varied; Lake and Southern zones recorded the highest counts compared to the Eastern zone. The cassava varieties assessed had influenced *M. tanajoa* counts while cropping systems had no effect on insect counts in both 2015 and 2016. Crop age and weather variables had influenced the survival, perpetuation and distribution of *M. tanajoa*. The relationship among the environmental variables, rainfall and temperature were negatively related to *M. tanajoa* counts in 2015 while in July 2016, only rainfall was negatively correlated to *M. tanajoa*.

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CHAPTER THREE

3.0 ENVIRONMENT AND WEATHER INFLUENCE ON OCCURRENCE AND DAMAGES OF *Mononychellus tanajoa* Bondar (Acarina: Tetranychidae) ON SELECTED CASSAVA VARIETIES IN THE LAKE ZONE, TANZANIA

3.1 Abstract

The study was conducted in the Lake Zone, the leading cassava producing Zone in Tanzania during the 2015 and 2016 dry seasons. It aimed at establishing the trend in occurrence of Cassava green mites (CGM), *M. tanajoa* and the influence of the weather variables on the pest's damage on commonly grown cassava varieties. The experiments were laid out in a Split plot design with varieties as sub plots and locations as main plots. The three locations were; Ukiriguru, Ng'ombe and Kishiri sites the former two being in Misungwi and later one in Kwimba districts respectively. There were eight commercial cassava varieties, Naliendele (NLD), Kiroba (KRB), Meremeta (MRM), Belinde (BLD), Suma (SUM), Mkombozi (MKZ), Kyaka (KYK) and Namikonga (NMK) as well as a popular local cassava Liongo Kwimba (LNG) variety. These were laid out in a Randomized Complete Block Design (RCBD) in three replications (9 x 3 = 27) making a total of twenty seven plots. Fields were ploughed, harrowed and ridged; all the recommended cassava management practices were followed accordingly. Data collected were the mites' counts and damages while weather data on temperatures, rainfall and relative humidity were collected from the Tanzania meteorological stations of Mwanza region of the Lake Zone. The influence of weather parameters on occurrence and perpetuation of *M. tanajoa* was analyzed through multiple regressions. *M. tanajoa* infestation was allowed to occur naturally. Results suggested that mites counts and damage varied significantly ($P \leq 0.05$) among dates, varieties, time of the year and locations in both years. Generally, Kishiri (0.46) in 2015 and Ukiriguru (0.93) in 2016 recorded the highest *M. tanajoa* counts while Ng'ombe (0.34) in 2015 as well Kishiri (0.88) had the lowest. The highest root (27680.00 tons/ha) yield was recorded at Ukiriguru in both seasons. Of the test varieties Liongo Kwimba (0.53 in 2015 and 0.59 in 2016), Naliendele (0.51 in 2015 and 0.52 in 2016), and Mkombozi 0.48 in 2015 and 0.53 in 2016 were comparatively the most susceptible. Rainfall ($\beta = -0.000574$, $p \leq 0.028$), relative humidity ($\beta = -0.0331$, $p \leq 0.003$), maximum temperature ($\beta = -0.1788$, $p \leq 0.002$), and minimum temperature ($\beta = 0.1449$, $p \leq 0.006$) have contributed either positively or negatively to the survival, perpetuation of and damage by *M. tanajoa* in both seasons.

Keywords: Varieties, Cassava, Population, Damage, Dynamics and *M. tanajoa*

3.2 Introduction

Arthropods variably respond to seasonally unfavourable environmental conditions, mainly heat, cold, or drought. Migration to over seasoning habitats, dormancy ranging from quiescence to diapause, and acquired hardiness are three common adaptations that arthropods have developed to cope with temporarily adverse climatic conditions (Zundel *et al.*, 2007). Several improved and commercial cassava varieties have been bred and officially released in Tanzania (mostly in 2010) targeting the yield and major diseases, but limited information exists on their response to the combined effect of *M. tanajoa* and the environment (Rwegasira, Personal communication, 2015).

Cassava is a subsistence food to 200 million people in the African continent and in the Brazil serves as food for millions of poor people and plays an important role in the generation of employment and income, especially for small and medium producers (Andre *et al.*, 2014). Since its first occurrence in East Africa, the pest has extended its distribution to the entire cassava growing belts, where it causes estimated yield losses ranging between 30-80 % (Yanninek *et al*., 1989).

Cassava green mite: *Mononychellus tanajoa* Bondar (Acari: Tetranychidae) is among the most important pests that attack cassava in Tanzania (Nyiira, 1972; Evila *et al*., 2012). *Mononychellus sp*. was first reported in the country in 1972 at Ukerewe Islands (Nyiira, 1972; Msabaha *et al*., 1988). It attacks mainly shoots and leaves of cassava reducing both photosynthetic rate and root dry matter (Nyiira, 1972). In the Lake zone, the pest is more devastating with losses ranging from 20% to 80% tuber yield loss if left uncontrolled (Anon, 1999). It is not known that if such variations are related to environmental differences or varied response of cassava varieties that are commonly grown.

Despite its importance and diverse use, cassava production in Tanzania (5.6 million metric tons) and the rest of African countries (149.5 million metric tons) is grossly low compared to world production statistics (256.5 million metric tons) (FAO, 2013). Several efforts have been made since mid-1980s by the Tanzanian National Root Crop Research Program and International organizations particularly the International Institute of Tropical Agriculture (IITA) to breed for new varieties with acceptable agronomic qualities mainly yield. From 1990s to date, the breeding efforts were diverted to management of viral diseases, the Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD). Such efforts have greatly addressed disease problems although has not improved the production to great extent. Excerpts in production data from early 2000s to date indicates that the cassava production in Tanzania ranged from 45 737 (in 2003) to 57.228 tons/ha (in 2012) which is far less than that of India, 262 400 (in 2003) and 364 770 tons/ha (in 2012) in Asian countries (FAO, 2013). As such many other biotic and abiotic production constraints remain to be addressed among which is cassava green mite. It attacks the shoots/leaves and reduces photosynthetic rate or the root dry matter (Moraes and Flechtmann, 2008). Severely damaged leaves dry out and fall off, which can cause a characteristic candle stick appearance Moreover, as a result of the reduced plant growth, starch in the storage roots is slowed and sometimes even reversed. The root yield losses in the absence of any control measures can reach up to 50% (Moraes and Flechtmann, 2008).

Studies that are geared towards understanding the ecology and the importance of the pest in relation to the environmental variables in the Lake Zone are scarce. The current studies aimed at establishing the occurrence of cassava green mites and the influence of the weather variables on the pest's damage on commonly grown cassava varieties in Tanzania. The outcome(s) could be useful in designing strategies to manage *M. tanajoa* to minimum damage threshold level and subsequent losses. Moreover, it will widen scope of knowledge of researchers, academicians and Agricultural extension workers in Tanzania.

3.3 Materials and Methods

3.3.1 Location of the study areas

Mwanza region is located in the Lake Zone, the leading cassava producing zone that accounts for about 37.43% of the total cassava in Tanzania, followed by the Southern zone, 26.50%; the Eastern zone, 12.36%; while other five zones produce only 24.15% of the cassava root yield in the country (TZNY, 2012). Three different field experiments (one experiment per site) were conducted in two consecutive years (2015 and 2016) to assess the environmental (different location) influence on the occurrence and damage of *M. tanajoa* on commercial and popular local cassava varieties. The three sites from two districts (Misungwi and Kwimba) namely, Ukiriguru was in controlled environment in the Lake Zone Agricultural Research and Development Institute (LZARDI) located at 02^0 43.156'S, 033^0 01.43'E and 4 000 m above sea level, Ng'ombe was chosen among the farmers' fields which were exposed to different cassava varieties located at 02^0 45.743'S and 033^0 01.838'E and 3 888 m above sea level (in Misungwi district) and Kishiri village was the driest site and where most farmers grow a common susceptible cassava variety (Liongo Kwimba) and the hit area of the mites located at 02^0 48.694'S, and 033^0 22.161'E and 4 023 m above sea level Kwimba districts were selected for the experiments (Fig. 4.1). Nine different cassava varieties of which eight are commercial varieties (Kyaka, Naliendele, Kiroba, Meremeta, Belinde, Suma, Mkombozi and Namikonga) and one local variety (Liongo Kwimba) were planted in experiments at each location. Kyaka variety is resistant and all the other seven varieties are moderately tolerant while Liongo Kwimba is susceptible to the mites. These were randomized into nine plots in a Split Plot Design with locations as main plots while varieties as sub plots, replicated three times making a total of twenty seven plots (9 x 3 = 27). Kyaka variety was considered as a check resistant to *M. tanajoa*. The treatments were allocated to plots of $36m^2$ with 1m path (border) between plots and 2m between blocks, respectively. One stem cutting (0.3 m long) was planted at a spacing of 1x1m within and between rows giving a total of 10 000 plant population ha^{-1} in a $1924m^2$ plot. Natural infestation with *M. tanajoa* was considered.

3.3.2 Data management and collection

3.3.2.1 Assessment of *Mononychellus tanajoa* population

Mononychellus tanajoa population was monitored at monthly intervals starting at three months after planting i.e from March and ending in September, 2015 respectively. This was taken by the physical counting of the mites on the top fully open five leaves using a hand lens (Model No. YT1045/50mm). In each plot, eighteen cassava plants within a net plot were sampled randomly for assessment while leaving out the border rows to avoid border effects (Evila *et al*., 2012).

3.3.2.2 Leaf damage assessment

The leaf damage was recorded using a scale of 1 to 5 as reported by Nukenine *et al*., (2002) with minor modifications i.e. 1 means no obvious symptom, 2 = less than 5% of leaf chlorosis, 3 = more than 5% but less than 50% of leaf chlorosis, 4 = more than 50% of leaf chlorosis with significant reduction in leaf area and 5 = leaf is dead and has dropped.

3.3.2.3 Statistical analysis

Collected data were subjected to analysis of variance (ANOVA) in a Split plot design using the GenStat software 15TH edition (GenStat, 2004). Treatment means were compared using the least significant difference (LSD) at 5% level of significance ($P \leq 0.05$). While all the numerical data with low counts or zero values were transformed to log y+1 (Eric, 2013). Yield data were taken in kilogrammes and converted into tons ha$^{-1.}$ Regression analysis was run to predict the effect of some weather variables on the counts and damage by *M. tanajoa*.

3.4 Results

Results obtained (Fig. 3.2) indicated that higher counts and damage were recorded in 2016 compared to 2015. Moreover, within the two years *M. tanajoa* counts and damage were found to be significant ($P \leq 0.05$) in 2015 with Kishiri recording the highest mites' population; followed by Ukiriguru while Ng'ombe had the lowest counts (Fig. 3.3).

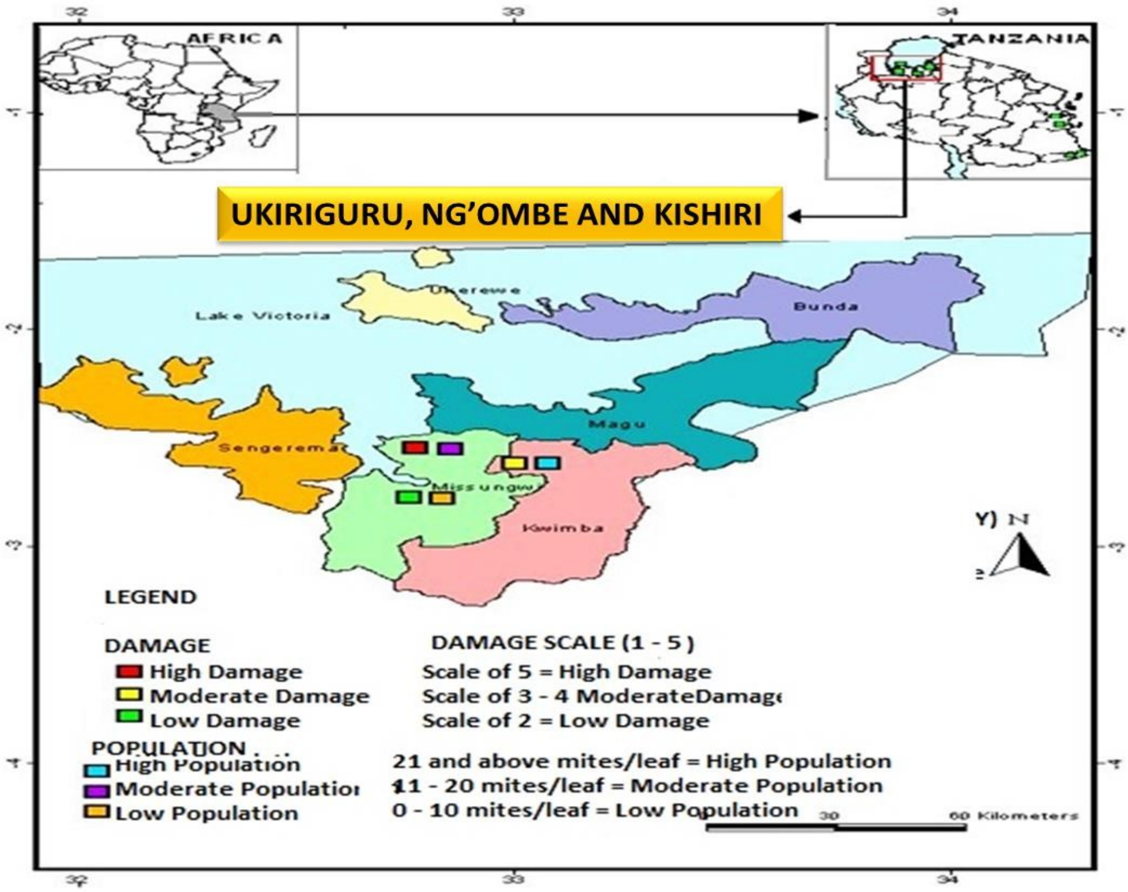
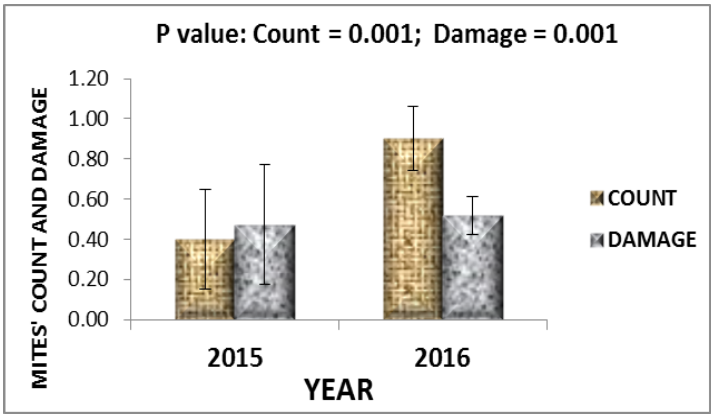


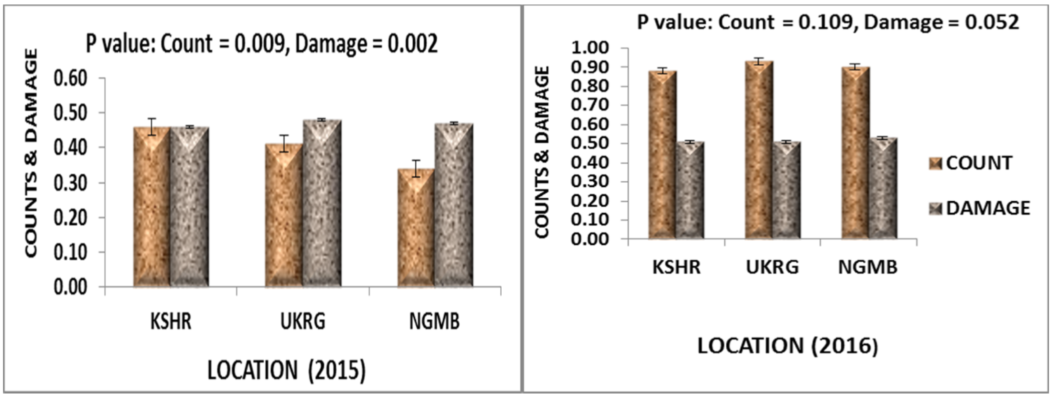
Figure 3.1: Map of Tanzania showing the study areas in Mwanza Region, Lake Zone

Conversely, Ukiriguru recorded the highest damage followed by Ng'ombe while Kishiri had the least damage. However, the counts and damage by cassava green mite were relatively higher in 2016 compared to 2015 despite the insignificant difference among the three locations. The damage by *M. tanajoa* was significantly different ($P \leq 0.05$) among the locations where Kishiri and Ukiriguru were statistically similar while Ng'ombe having the highest damage.



SD±: COUNTS (2015) = 0.247, DAMAGE = 0.298 COUNTS (2016) = 0.157, DAMAGE = 0.094

Figure 3.2: *Mononychellus tanajoa* counts and damage during 2015 and 2016

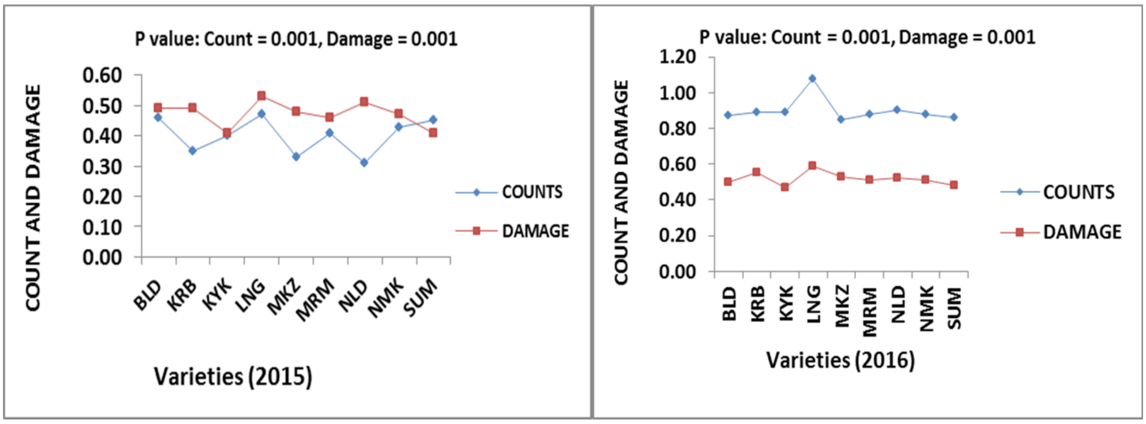


SE±: Counts = 0.009 Damage = 0.002; SE±: Count = 0.109 Damage = 0.052

KEY: KSHR = Kishiri, UKRG = Ukiriguru, NGMB = Ng'ombe

Figure 3.3: *M. tanajoa* counts and damage in three locations of Mwanza region, Tanzania

The observed response of some cassava varieties to *M. tanajoa* in 2015 and 2016 was as shown in Fig. 3.4. There were significant (P≤0.05) differences among the cassava varieties on the counts and damage caused by *M. tanajoa* in both years. The variety Liongo Kwimba recorded the highest mite's counts and damage in both years while Naliendele recorded the lowest mite counts. However, Kyaka and Suma appeared to have the least damage in 2015.



SE±: Count = 0.025 Damage = 0.017 SE±: Count = 0.033 Damage = 0.010

Figure 3.4: Counts and damage by cassava green mite on commercial and popular cassava varieties in Mwanza region, Tanzania

The performance of some cassava varieties to *M. tanajoa* counts in three locations were found to be significant (P≤0.05) (Fig. 3.5). In 2015, Belinde and Liongo Kwimba varieties generally recorded higher mites' counts while Mkombozi and Naliendele had the lowest number of *M. tanajoa* across the locations. Similarly in 2016, Liongo Kwimba recorded the highest counts of mites in all the three locations followed by Naliendele, Kyaka and Kiroba. The lowest mite counts were recorded on Suma, Namikonga and Mkombozi at all the three study sites.

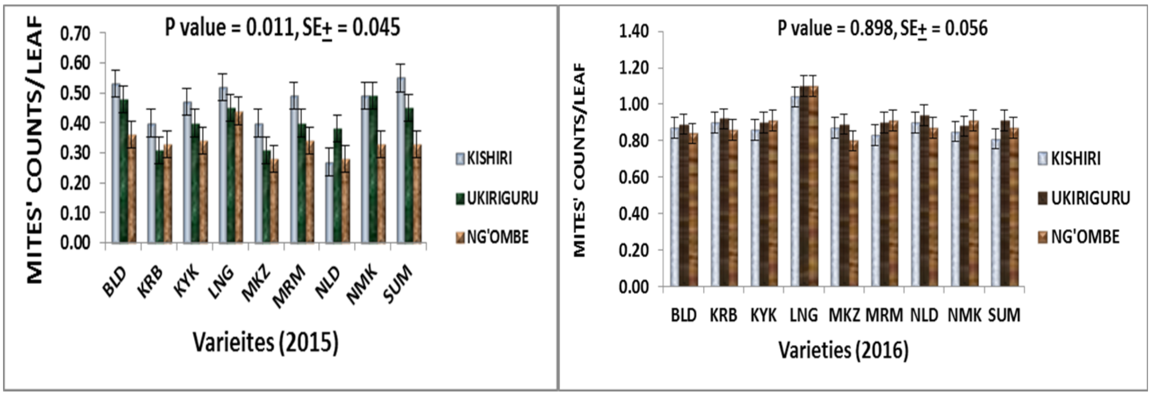


Figure 3.5: The *M. tanajoa* counts on tested cassava varieties among the three experimental sites in Mwanza

The effects of the interaction between cassava varieties and location on the damage by *M. tanajoa* were significant (P≤0.05) in both years (Figures 3.6, 3.7). However, in 2015, Liongo Kwimba recorded higher damage across the locations followed by Naliendele and Belinde with Suma having the lowest damage compared to other varieties. Similarly, Liongo Kwimba and Kiroba recorded higher damage in all the three locations in 2016 and Kyaka was found to have the least damage among all other varieties (Fig. 3.7).

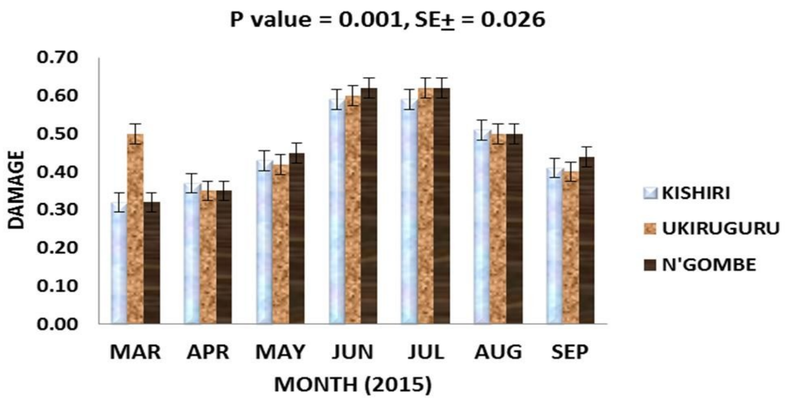


Figure 3.6: Interaction effects of cassava varieties and location on damage by *M. tanajoa* in the Mwanza region, Tanzania in 2015

Figure 3.8 shows that the interactions among time (months) and locations were significant in both years. Initially the mite counts were first observed in March, when the sampling started and when the rainfall declined. The mite's counts were higher especially at Kishiri but decreased subsequent months, especially at Ng'ombe and Ukiriguru at irregular intervals with its peak at Kishiri in August and June but drastically decreased to the lowest in July.

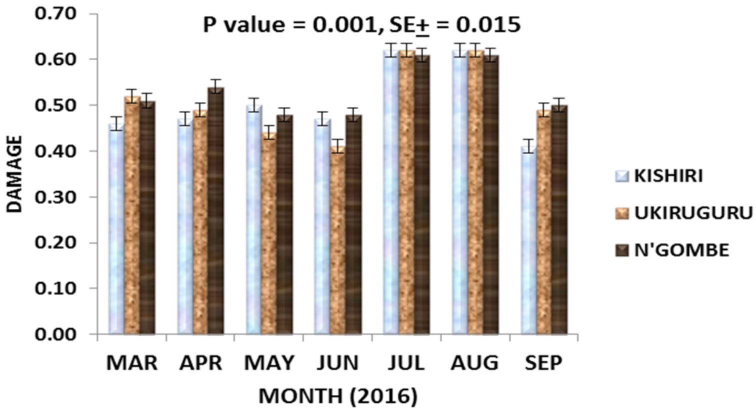


Figure 3.7: Interaction of cassava varieties and location on damage by *M. tanajoa* in the Mwanza region, Tanzania in 2016

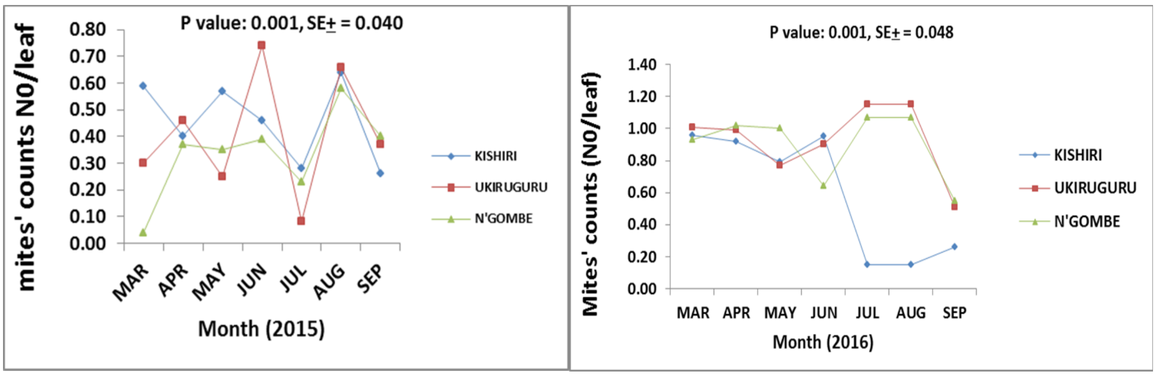


Figure 3.8: Interaction of time (months) and location on *M. tanajoa* counts during 2015 and 2016 in Mwanza region, Tanzania

Multiple regression analysis was conducted to predict the effects of the weather variables on the counts and damage by *M. tanajoa* in 2015 and 2016 (Table 3.1). Four weather variables (rainfall, relative humidity, and maximum and minimum temperatures) were simultaneously entered into the analysis and a question what was the percentage contribution of each of the dependent variables to the counts and damage of *M. tanajoa*. The overall variance explained by the three predictors was 1.1% in 2015 and 34.3% in 2016 which means that all the predictors accounts for 1.1% (in 2015) and 34.3% (in 2016) variance to *M. tanajoa* counts.

Table 3.1: Regression analysis of some weather variables against *M. tanajoa* counts during 2015 and 2016 in Mwanza region, Tanzania

2015 COUNTS				**2016 COUNTS**		
Parameter	**Beta (β Value)**	**SE±**	**P Value**	**Beta (β Value)**	**SE±**	**P Value**
Constant	4.80	1.37	(0.001)**	-7.99	1.16	(0.001)**
Rainfall	-0.000022	0.0000750	(0.976)*	-0.11429	0.00834	(0.001)**
RH	-0.0331	0.0110	(0.003)**	-0.02773	0.00286	(0.001)**
Max. Temp	-0.1788	0.0566	(0.002)**	0.1273	0.0239	(0.001)**
Min. Temp	0.1449	0.0523	(0.006)*	0.3840	0.0371	(0.001)**

Figures in parentheses are P values (significant at ≤0.005)

Key: RH = Relative Humidity, Max. Temp. = Maximum Temperature, Min. Temp. = Minimum Temperature

Rainfall, relative humidity and maximum temperature were negatively correlated while minimum temperature was positively related to *M. tanajoa* counts in 2015 such as rainfall (β = -0.0000022, p ≤0.976), relative humidity (β = -0.0331, p≤0.003), maximum temperature (β = -0.1788, p≤0.002), and minimum temperature (β = 0.1449, p≤0.006), however, rainfall was not significant. This suggests that with increase in a unit of each variable (relative humidity and maximum temperature) *M. tanajoa* counts decreases.

Table 3.2: Regression analysis of some weather variables against *M. tanajoa* damage during 2015 and 2016 in Mwanza region, Tanzania

DAMAGE 2015				**DAMAGE 2016**		
Parameter	**Beta (β Value)**	**SE±**	**P Value**	**Beta (β Value)**	**SE±**	**P Value**
Constant	3.890	0.702	(0.001)**	-1.159	0.353	(0.001)**
Rainfall	-0.000786	0.000134	(0.001)**	-0.02350	0.00255	(0.001)**
RH	-0.00100	0.00567	(0.860)	-0.013411	0.0087	(0.001)**
Max. Temp	-0.0704	0.0291	(0.016)*	0.01907	0.00728	(0.009)**
Min. Temp	-0.0692	0.0268	(0.010)*	0.1015	0.0113	(0.001)**

Figures in parentheses are P values (significant at ≤0.005)

Key: RH = Relative Humidity, Max. Temp. = Maximum Temperature, Min. Temp. = Minimum Temperature

The relationship among the weather variable was significant ($P \leq 0.05$). All the parameters tested Rainfall, relative humidity; maximum and minimum temperatures had negatively influenced *M. tanajoa* damage in both years, while maximum and minimum temperatures were positively related to *M. tanajoa* damage in 2016 (Table 3.2).

3.5 Discussion

The difference in mites' counts and damage between years could be due to the higher temperatures recorded in 2015 compared to 2016. Moreover, other factor such as differences in varieties and other environmental variables especially rainfall and relative humidity had contributed to the perpetuation and damage by *M. tanajoa*. The higher mite counts at Kishiri in 2015 could be attributed to so many factors as Kishiri is considered the hit mite area and Liongo Kwimba (a susceptible variety) is dominantly cultivated. It is also the driest among the locations, a favourable condition for *M. tanajoa* perpetuation and development, thus high mite density. Initially the mite counts were first observed in March, when the sampling started and when the rainfall declined. This could make it higher especially at Kishiri but decreased to a certain level in subsequent months, especially at Ng'ombe and Ukiriguru at irregular intervals. This indicated that the dynamics of the mite's counts across locations was irregular with its peak at Kishiri in August and June but drastically decreased to the lowest in July. This was also reported by Toko *et al*., (1996) that high *M. tanajoa* densities were proved to occur in an irregular pattern. Also several authors (Yaninek *et al*., 1989; Onzo *et al*., 2005; Hanna *et al*., 2005) reported that limited availability of fresh plant growth (during the main part of the dry season) and heavy rainfall (in the middle of the rainy season) are the factors keeping the pest populations low. Moreover, the damage was observed to fluctuate as reported by Nukenine *et al*. (2002).The fluctuations in damage by *M. tanajoa* within and across years could be attributed to differences in weather variables over time and space as well as inherent differences among the tested cassava varieties. It was interestingly observed that the mites' counts were higher in Ukiriguru and Kishiri while moderate damage was recorded in both locations (Fig. 3.1). This could be due to the fluctuations in rainfall and/or the responses of the different cassava varieties planted in the areas and it implies that the damage didn't correspond to the higher counts recorded in the two sites. However, Ng'ombe recorded lower mites' counts and damage. Similar observation was also reported by Nukenine *et al*. (2002).

Generally, the counts and damage were higher in 2016 compared to 2015 which could be a result of the higher amount of relative humidity in 2015. Several researchers (Onzo *et al*., 2005; Hanna *et al*., 2005; Teodoro *et al*., 2009a, b) reported a negative correlation between rainfall and mites' counts. This could be due to the fact that the population build-up of the pest started at the onset of the dry season or close end of the rainy season which is May, while July to August were the peak periods and thus, the damage was subsequently higher. The damage led to high loss of the cassava leaves and subsequent reduction in the photosynthetic ability of the cassava and the yield, especially on the susceptible varieties. This has been reported by other researchers that the damage has been equated to the loss of biomass and is an indicative loss of the foliar photosynthetic area (Akinlosotu and Leushner, 1981). The varietal differences could be attributed to their inherent resistance/tolerance and/or susceptibility to the mites' damage as reported by Toko *et al*. (1996) that the variation in *M. tanajoa* population density among the genotype may be associated with factors inherent in the different genotypes.

The variations among in either positive or negative relationship between the two years could be attributed to the differences in amount of rainfall, relative humidity and temperatures received in each year thus, in both years there were higher amount of rainfall which if increased that will negatively affects the mites' counts. This indicated that with increase in a unit in rainfall will subsequently decrease mites' damage and vice versa.

3.6 Conclusion

The findings from the field experiments suggested that the trend had indicated limited influence of locations on the *M. tanajoa* counts. Most of the tested cassava varieties sustained great counts of *M. tanajoa* and were susceptible while Kyaka and Meremeta varieties were resistant. The highest *M. tanajoa* counts were recorded during the dry season in both years. Cassava green mite counts were also higher on young cassava plants compared to others. Rainfall had negatively while temperature positively influenced the survival, perpetuation of and subsequent damages by *M. tanajoa* in both years.

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CHAPTER FOUR

4.0 RESPONSE OF SELECTED CASSAVA VARIETIES TO *Mononychellus tanajoa* Bondar (Acarina: Tetranychidae) INFESTATION IN TANZANIA

4.1 Abstract

Three field experiments were conducted at three locations in Mwanza region in the Lake Zone of Tanzania namely; Ukiriguru (020 43.156'S, 0330 01.43'E and 4000m asl., N'gombe (020 45.743'S, 0330 01.838'E and 3888m asl.) and Kishiri (020 48.694'S, 0330 22.161'E and 4023m asl.) villages. The studies aimed at evaluating the responses of eight commercial cassava varieties viz: Naliendele (NLD), Kiroba (KRB), Meremeta (MRM), Belinde (BLD), Suma (SUM), Mkombozi (MKZ), Kyaka (KYK) and Namikonga (NMK) as well as a popular local cassava Liongo Kwimba (LNG) variety to *M. tanajoa* during the 2014/2015 and 2015/2016 wet and dry seasons. These were laid out in a Randomized Complete Block Design (RCBD) in three replications (9 x 3 = 27) making a total of twenty seven plots. Each treatment was allocated to a plot size of 36 m^2. Separation distance of 1m path between plots and 2m between blocks was maintained. One stem cutting (0.3m long) was planted at a spacing of 1x1m within and between rows giving a total of 10 000 plant population ha^{-1}. Infestation with *M. tanajoa* was allowed to occur naturally. Data on leaf damage and malformation were recorded using a scale of 1 – 5 as reported by Nukenine *et al*. (2002).

The results revealed that all the tested cassava varieties variably responded to mite damages with subsequent leaf malformation ($P \leq 0.001$). The variations were significant within and between years. Generally, the leaf damage and leaf malformation were higher in 2016 compared to 2015. Cassava varieties, Kyaka and Suma recorded the least damages while Liongo Kwimba suffered most damage among all the varieties tested. Despite the varied response to damages the tested yield components (root number and root weight) did not vary significantly although var., Kyaka and Meremeta recorded relatively higher yield. Therefore, future effort should be geared at breeding for tolerance to *M. tanajoa* to improve the adapted local varieties especially Liongo Kwimba.

Keywords: *M. tanajoa,* Cassava varieties, Damage, Leaf malformation, Responses.

4.2 Introduction

Cassava (*Manihot esculenta* Crantz: Euphorbiaceae) also known as Yuca (Spanish), mandioca (Portuguese), tapioca and manioc (French), Rogo (Hausa) and Muhogo (Swahili) is a tropical and subtropical short-lived perennial shrub originating from Latin America, most probably the Amazon region (Pellet and El-Sharkawy, 1997). It is grown throughout the Tropics from wet equatorial forest to drier areas where annual rainfall is at least 500 mm. The crop is grown in over 39 African countries, of which Nigeria, Democratic Republic of Congo, Ghana, Angola, Mozambique, United Republic of Tanzania, Uganda and Malawi are among the top twenty (20) producers in the world (FAOSTAT, 2013). Throughout Africa, cassava is used as food (fresh, boiled or flour) and source of starch for industrial purposes. Cassava leaves are nutritious vegetables in some countries and can also be used as animal feed. Tanzania is currently ranked the sixth producer of cassava in Africa and annual root production is estimated at 5 462 454 tons from 761100 hectares (FAOSTAT 2014) which is equivalent to 7.177 t/ha root productivity.

Cassava green mite: *Mononychellus tanajoa* Bondar (Acari: Tetranychidae) is among the most important pests that attack cassava in Tanzania (Evila *et al*., 2012; Nyiira, 1972). *Mononychellus sp*. was first reported in the country in 1972 at Ukerewe Islands (Nyiira, 1972; Msabaha *et al*., 1988). It attacks mainly shoots and leaves of cassava reducing both photosynthetic rate and root dry matter (Nyiira, 1972). In the Lake zone, the pest is more devastating with losses ranging from 20% to 80% tuber yield loss per plant if left uncontrolled (Moraes and Flechtmann, 2008). Until recently *M. tanajoa* was reported to have spread throughout the country, although at varied incidences among the major agro-ecological zones. There is need to know whether such variations are related to environmental differences, variable cassava varieties grown or the *M. tanajoa* species in Tanzania that are expected to be genetically diverse.

Lake Zone in Tanzania is the leading cassava producing zone that accounts for about 37.43% of the total cassava in the country, followed by the Southern zone, 26.50%; the Eastern zone, 12.36%; while other five zones produce only 24.15% of the cassava root yield in the country (TZNY, 2012). Despite its diverse use and economic value, cassava production in Tanzania (5.6 million metric tons) is below the world's standard and the harvested area of 1 061 043 ha while some African countries like Nigeria and Angola produce (57.1 and 9.9 million metric tons respectively) compared to the world production statistics (27.7 million metric tons). Therefore, cassava productivity in the country is as low as (5.236 t/ha) (FAOSTAT, 2016). Several efforts were been made since mid1980s by the Tanzanian National Root Crop Research Program and International organizations particularly the International Institute of Tropical Agriculture (IITA) to breed for new varieties with acceptable agronomic qualities mainly yield. From 1990s to date, the breeding efforts were diverted to management of viral diseases, the Cassava Mosaic Disease (CMD) and Cassava Brown Streak Disease (CBSD). Such efforts have greatly addressed disease problems although has not improved the production to great extent. Excerpts in production data from early 2000s to date indicate that the cassava production in Tanzania ranges from 457 37 (in 2003) to 572 28 tons ha^{-1} (in 2012) which is far less than that of India, 262 400 (in 2003) and 364 770 tons ha^{-1} (in 2012) in Asian countries (FAOSTAT, 2013). As such many other biotic and abiotic production constraint remain the most important of which is cassava green mite. The mite attacks shoots/leaves and reduces photosynthetic rate or root's dry matter (Anon, 1999). Severely damaged leaves dry out and fall off, which can cause a characteristic candle stick appearance. The root yield losses in the absence of any control measures can reach up to 50% (Anon, 1999).

Several improved and commercial cassava varieties such as Mkombozi, Kyaka, Kiroba, and Suma (E. Kanju, Personal communication, 2016) have been bred and officially released in Tanzania targeting the improved yield and resilience to major diseases, but limited information exist on their response to *M. tanajoa*. Studies that are geared towards understanding the ecology and the importance of the pest are scarce. The envisioned benefit captures how the identification of relatively tolerant cassava varieties would add value to overall cassava production in Tanzania.

4.3 Materials and Methods

4.3.1 Locations of the study

The experiments were conducted in the Lake zone for two consecutive years, 2015 and 2016. The three sites, Ukiriguru (020 43.156'S, 033^0 01.43'E and 4 000 masl (metres above sea level)) Lake Zone Agricultural Research and Development Institute (LZARDI), Ng'ombe (020 45.743'S and 033^0 01.838'E and 3 888 masl) and Kishiri (020 48.694'S, and 033^0 22.161'E and 4 023 masl) villages of Misungwi and Kwimba districts, respectively, were selected for the experiments. The sites were chosen due to their well-known history in cassava production in the country. Nine different cassava varieties namely Kyaka, (KYK), Naliendele, (NLD), Kiroba (KRB), Meremeta, (MRM), Belinde, (BLD), Suma (SUM), Mkombozi, (MKZ) and Namikonga (NMK) of which the former are commercial and improved varieties while Liongo Kwimba (LNG) is a local check. Kyaka variety was considered as a check resistant to *M. tanajoa*. These were planted at each location and randomized into nine plots using a Randomized Complete Block Design (RCBD) and replicated three times, making a total of twenty seven plots (9x3 = 27). The treatments were allocated to a plot size of 36m^2 with 1m path border between plots and 2m between blocks respectively. One stem cutting (0.3m long) was planted at a spacing of 1x1m within and between rows giving a total of 10 000 plant population ha^{-1} in a 1924 m^2 plot. This was allowed under natural infestation by the mites.

4.3.2 Parameters assessed

Leaf damage and malformation assessment

The leaf damage was recorded using a scale of 1 to 5 modified from Nukenine *et al*., (2002). 1 = no obvious symptoms, 2 = less than 5% leaf chlorosis and the leaf was damaged but no malformation, 3 = more than 5% but less than 50% leaf chlorosis and mild malformation, 4 = more than 50% leaf chlorosis with significant reduction in leaf area and severe malformation with significant reduction in shape and 5 = leaf is 100% distorted or dead and dropped.

4.3.3 Statistical analysis

All data collected were subjected to two way analysis of variance (two way ANOVA) in a Randomized Complete Block Design where locations were used as blocks, time and varieties as factors (Gomez and Gomez, 1984). The software GenStat 15th edition was used for the analysis (GenStat, 2004). Treatment means were compared using the Least Significant Difference (LSD) at 5% level of significance ($p \leq 0.05$) while all the numerical data with low counts or zero values were transformed to log y + 1(Eric, 2013). Yield data were taken in kilograms ha^{-1}.

Table 4.1: Cassava varieties used for the experiments and their history

Variety	**Type**	**Maturity**[1]	**Pest Status**	**Year Released**	**Yield Potential**
Kyaka	Improved	Early	Resistant	2010	Medium
Meremeta	Improved	Early	Tolerant	2010	Medium
L/Kwimba	Local	Early	Susceptible	None	Medium
Namikonga	*B/Line	Medium	M/ tolerant	None	Medium
Mkombozi	Improved	Early	Susceptible	2010	High
Naliendele	Improved	-	M/ tolerant	-	-
Kiroba	Improved	Early	Tolerant	-	High
Suma	Improved	Early	Tolerant	2010	Medium
Belinde	Improved	Early	S/tolerant	2010	Medium

Source: (E. Kanju, Personal communication, 2016)

Note:*It is thought to be an Amani hybrid from the Amani cassava breeding program by British in 1930s (Hillocks and Jennings 2003, Jennings 1957)
[1]Early means 8-12 months while late is 15 months and above
Key: *B/Line = *Breeding line; M/tolerant = Moderately tolerant; S/tolerant = Slightly tolerant

Figure 4.9: Leaf Damage assessment scale (1 – 5) for *M. tanajoa*

4.4 Results

The result shows the leaf damage by *M. tanajoa* to some cassava varieties in the Lake Zone during the 2015 cassava growing season (Fig. 4.2). There were significant differences among the cassava varieties on leaf damage caused by *M. tanajoa* (p ≤0.001, n = 9, df = 8, LSD_{005}= 0.043). Generally, significant and higher leaf damages were recorded in July, June and August respectively ($p \leq 0.001$, n = 9, df = 8, LSD_{005}= 0.037). The damage then started to decline in August while March and April recorded the least leaf damage. Moreover in March, higher damage was recorded where Naliendele, Kiroba and Liongo Kwimba were the most damaged varieties. Liongo Kwimba recorded the highest leaf damage followed by Naliendele and Kiroba in 2015. However, Kyaka and Suma appeared to have the least leaf damage. Other months across varieties were found to have recorded similar leaf damage. The interaction of varieties and months was highly significant ($p \leq 0.001$, n = 9, df = 8, LSD_{005}= 0.112). Liongo Kwimba and Mkombozi cassava varieties were much damaged especially in June and July while Kyaka and Suma were the least damaged especially in March to May.

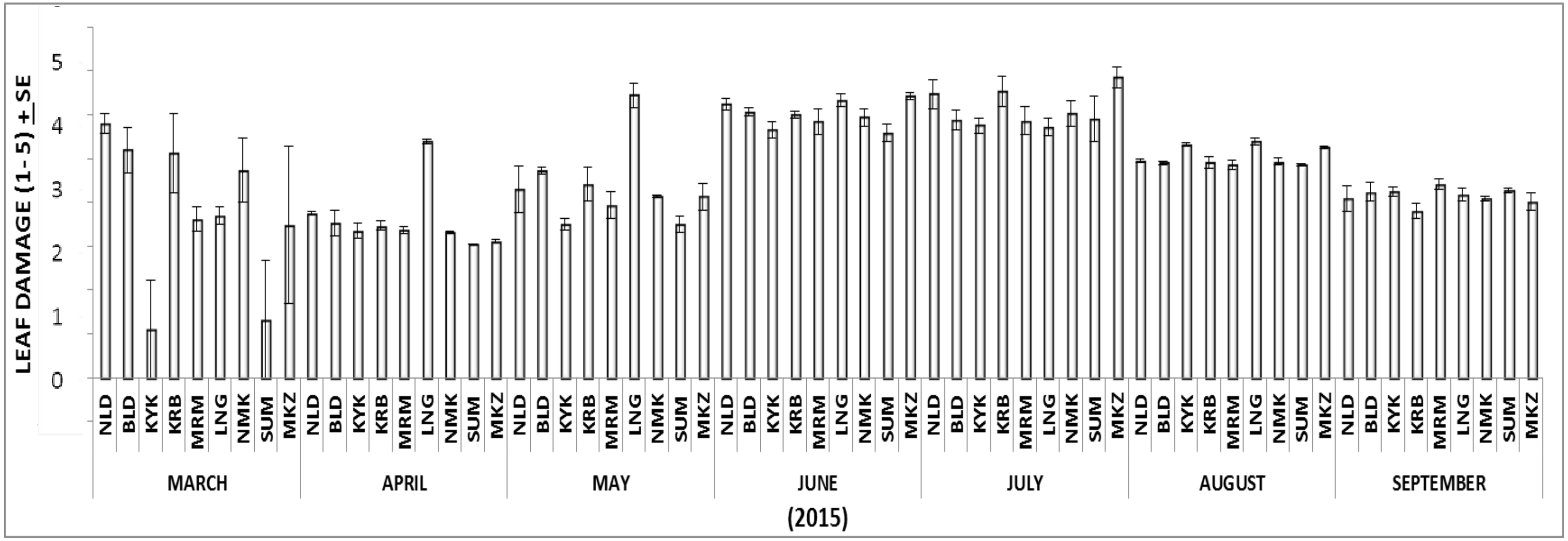

Figure 4.10: Leaf damage by *M. tanajoa* during the 2015 growing season in the Lake Zone, Tanzania

Key: NLD = Naliendele, BLD = Belinde, Kyk = Kyaka, KRB = Kiroba, LNG = Liongo Kwimba, NMK = Namikonga, SUM = Suma, MKZ = Mkombozi

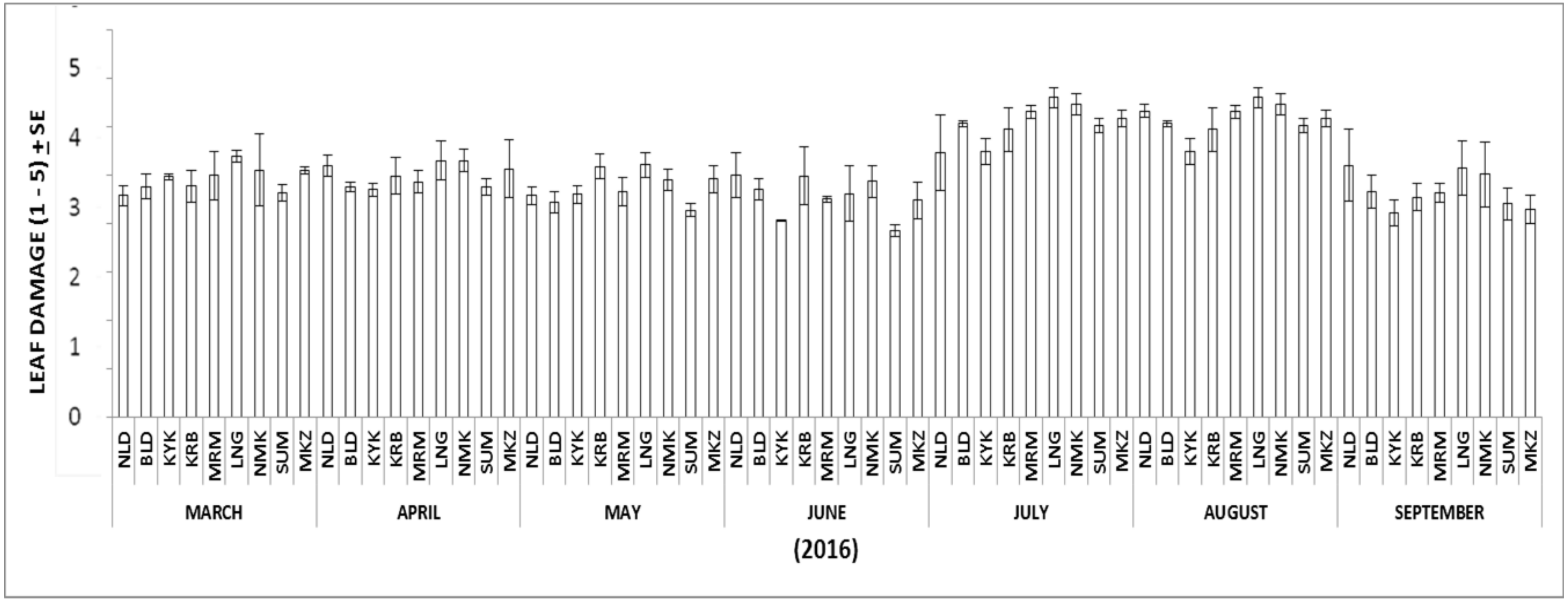

Figure 4.11: Leaf damage by *M. tanajoa* during the 2016 growing season in the Lake Zone, Tanzania

Key: NLD = Naliendele, BLD = Belinde, Kyk = Kyaka, KRB = Kiroba, LNG = Liongo Kwimba, NMK = Namikonga, SUM = Suma, MKZ = Mkombozi

The leaf damage on some cassava varieties caused by *M. tanajoa* was found to be highly significant ($p \leq 0.001$, n = 9, df = 8, LSD_{005}= 0.024). In 2016, the leaf damage was varied among the cassava varieties. Liongo Kwimba and Namikonga recorded higher leaf damage while Kyaka and Suma were relatively lower (Fig. 4.3).

The effects of the time interval (months) on the cassava varieties was also statistically significant ($p \leq 0.001$, n = 9, df = 8, LSD_{005}= 0.021). The highest leaf damage by *M. tanajoa* was recorded in July and August in 2016. Other months across years were found to have recorded similar leaf damage. The interaction of time interval and cassava varieties was not significant.

Similarly, in 2015, leaf malformation by *M. tanajoa* on commercial cassava varieties was highly significant ($p \leq 0.001$, n = 9, df = 8, LSD_{005}= 0.153) (Fig. 4.4). The influence of time interval on cassava leaf malformation was also highly significant where Mkombozi, Naliendele and Liongo Kwimba recorded the highest leaf malformation ($p \leq 0.001$, n = 9, df = 8, LSD_{005}= 0.135). The leaf malformation varied among cassava varieties especially in June and July compared to all other months. However, this was followed by Kiroba variety while Kyaka and Suma appeared to have recorded the least leaf malformation. It was initially very low from March to May and declined sharply in August and September. The interaction of time interval (months) and cassava varieties was not statistically significant.

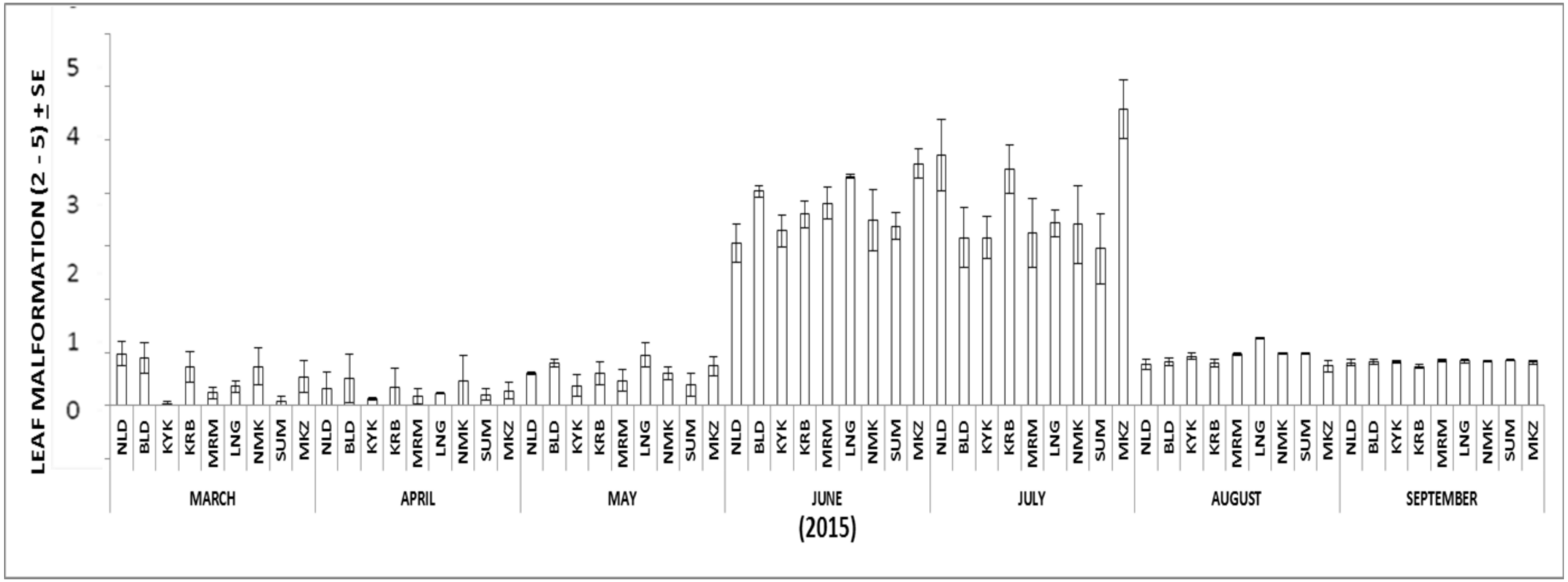

Figure 4.12: Leaf malformation by *M. tanajoa* during the 2015 growing season in the Lake Zone, Tanzania

Key: NLD = Naliendele, BLD = Belinde, Kyk = Kyaka, KRB = Kiroba, LNG = Liongo Kwimba, NMK = Namikonga, SUM = Suma, MKZ = Mkombozi

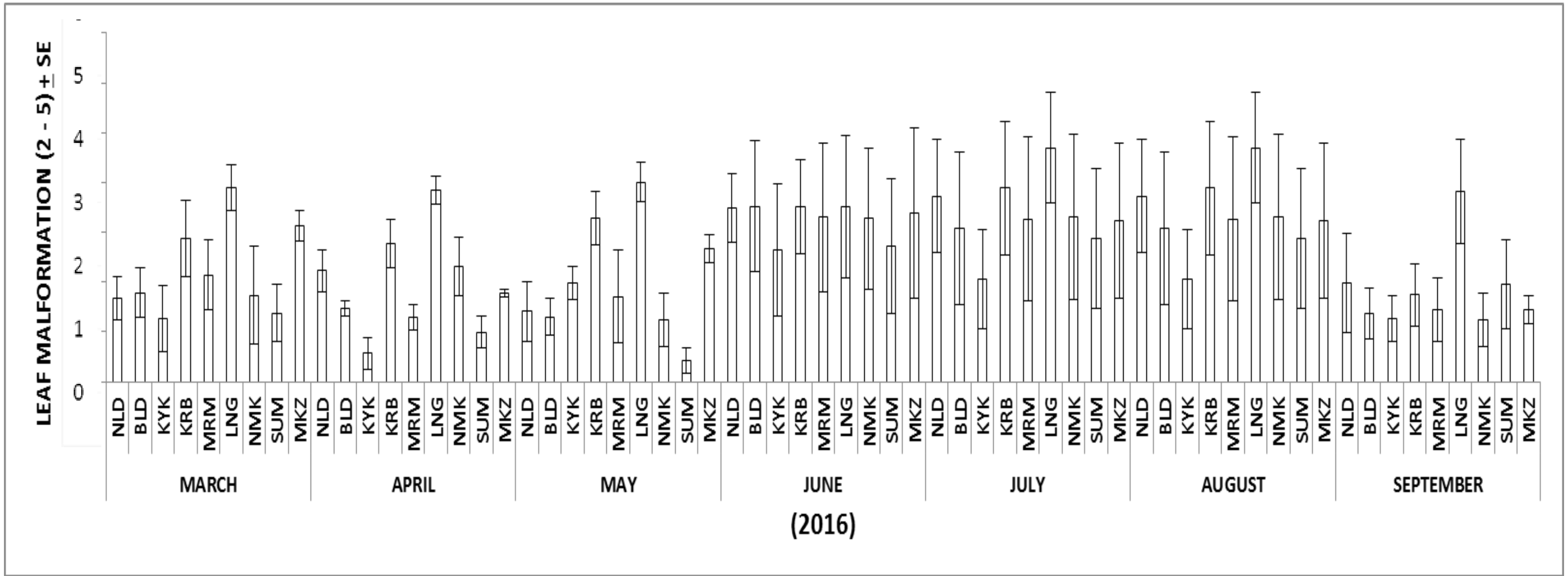

Figure 4.13: Leaf malformation by *M. tanajoa* during the 2016 growing season in the Lake Zone, Tanzania

Key: NLD = Naliendele, BLD = Belinde, Kyk = Kyaka, KRB = Kiroba, LNG = Liongo Kwimba, NMK = Namikonga, SUM = Suma, MKZ = Mkombozi

Considering the damage inflicted by *M. tanajoa* with reference to leaf malformation in 2016, the differences were highly significant among the cassava varieties ($p \leq 0.001$, n = 9, df = 8, LSD_{005}= 0.099) (Fig. 4.5). Generally, the responses of the cassava varieties were so much variable. Cassava varieties Liongo Kwimba and Kiroba leaves were highly malformed compared to all other varieties while Kyaka and Suma were those that have recorded least leaf malformation. Moreover, time interval (months) had significantly influenced leaf malformation among the cassava varieties ($p \leq 0.001$, n = 9, df = 8, LSD_{005}= 0.087). Initially the malformation was low and varied among varieties (March to May), and started to rise in June peaking in July and August which subsequently declined in September. The interaction between time interval and the cassava varieties was not significant.

The average root number per stand did not significantly differ among the cassava varieties tested in 2015 (Fig. 4.6). Cassava varieties, Meremeta and Kyaka recorded the highest root number compared to other varieties. However, cassava variety, Naliendele recorded the least root number while other varieties were found to be similar. Similarly, there were no statistical differences among the cassava varieties tested as per root weight per plot (Fig. 4.7). However, Kyaka recorded the highest (4324 t/ha) root weight compared to all other varieties while the other eight varieties were statistically similar. Liongo Kwimba proved to be inferior among all varieties (951 t/ha).

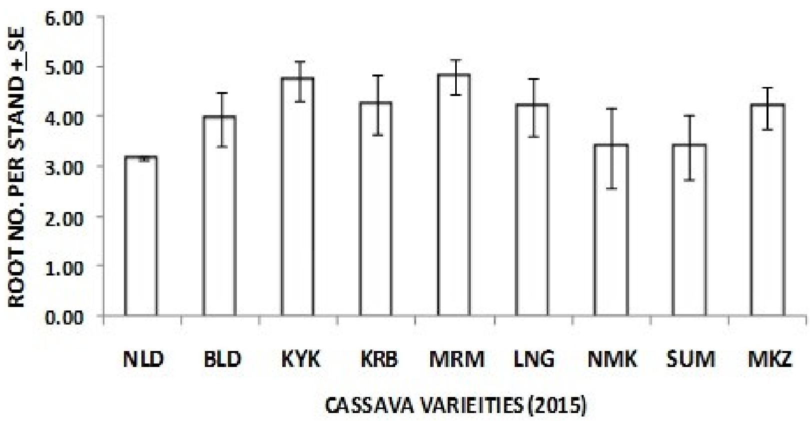

Figure 4.14: Shows the average cassava root number per stand in the Lake Zone, Tanzania during the 2015 cassava growing season.

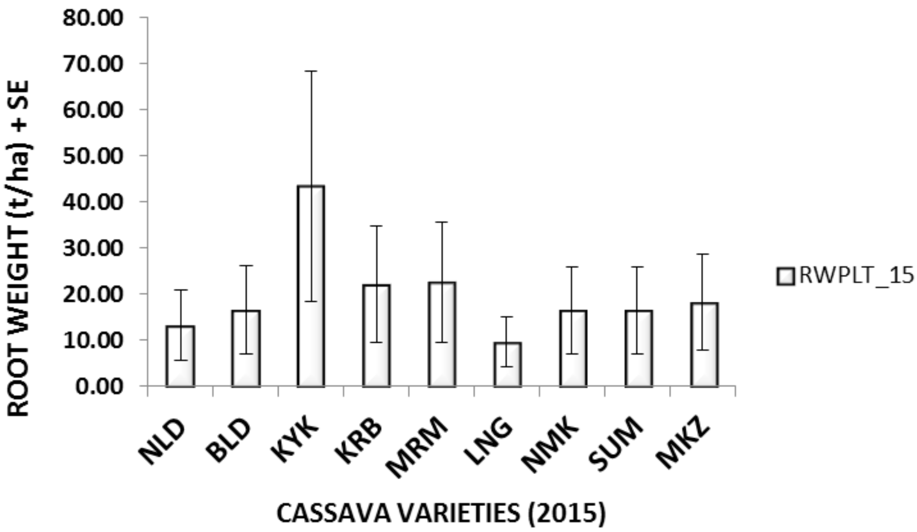

Figure 4.15: Shows the average cassava root weight (t/ha) in the Lake Zone, Tanzania during the 2015 cassava growing season.

Moreover, in 2016, the average cassava root number per stand was insignificantly different among the cassava varieties tested (Fig. 4.8). Cassava varieties, Meremeta and Kyaka recorded the highest root number compared to other varieties across the two growing seasons. However, Naliendele recorded the least root number while other varieties were found to be similar. Moreover, the average cassava root weight (t/ha) did not significantly (Fig. 4.9) differ among the cassava varieties tested however, Kyaka recorded the highest (4454 t/ha) root weight compared to other varieties however Liongo Kwimba appeared to have recorded the least cassava root weight (1075 t/ha).

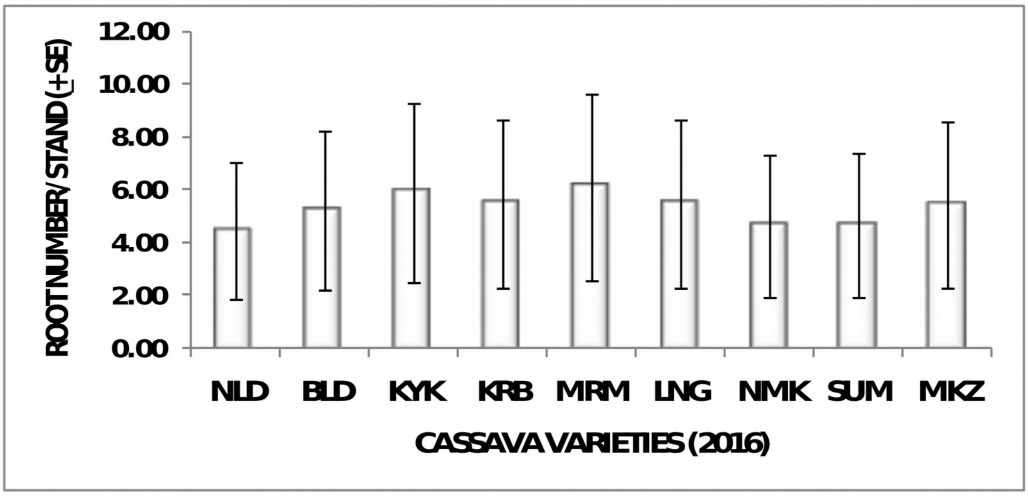

Figure 4.16: Shows the average cassava root number per stand in the Lake Zone, Tanzania during the 2016 cassava growing season.

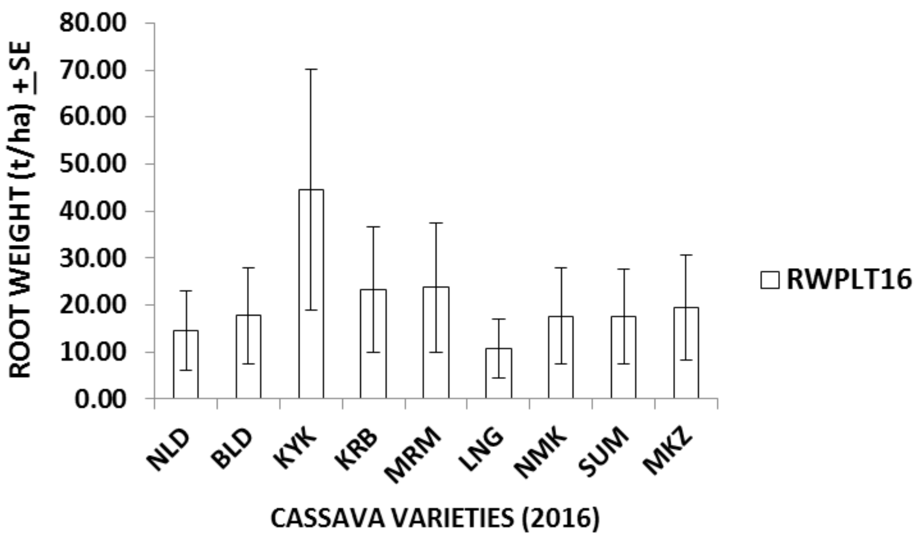

Figure 4.17: Shows the average cassava root weight (t/ha) in the Lake Zone, Tanzania during the 2016 cassava growing season.

4.5 Discussion

The differences observed on the cassava varieties as a result of leaf damage and malformation and the other factors like rainfall, temperature and relative humidity across years were due to the differences that exist among the varieties. In both the years, Kyaka and Suma cassava varieties have recorded the least damage compared to all other varieties which could be due to their inherent ability (Peter, 2011) to resist or tolerate the attack and subsequently damage by the mites. This could be attributed to their inherent resistance/tolerance and/or susceptibility to the mites' damage. Similar result was reported by (Toko *et al*., 1996) that the variation in *M. tanajoa* damage among the genotypes may be associated with factors inherent in the different genotypes. More so, the ability of the two varieties to perform better might be as a result of the non-preference of the varieties by the mites. Several researchers have reported that the low damage and incidence recorded for CGM throughout the observation periods in a high infection pressure area such as Ibadan is a remarkable indication of promising levels of field resistance present in Potential of Cassava Landraces (Adebola *et al*., 2008).

Generally, the damage was higher in 2015 compared to 2016 which could be as a result of the variations in weather variables that affected the build-up of mites' number. Several researchers (Onzo *et al*., 2005; Hanna *et al*., 2005; Teodoro *et al*., 2009a,b) have reported a negative correlation between rainfall and number of mites. This could be due to the fact that the population build-up of the pest started at the onset of the dry season or closure of the rainy season which is May, while July to August were the peak periods and thus, the damage become higher. Moreover, the fluctuations in damage within and across years could be attributed to differences in weather variables over time and space (Evila *et al*., 2012).

According to Akinlosotu and Leuschner (1981), the damage has been equated to the loss of biomass and is an indicative of loss of the leaf photosynthetic area. Therefore, the leaf damage and malformation led to high loss of the cassava leaves and subsequent reduction in the photosynthetic ability of the cassava and the yield, especially on the susceptible varieties like Liongo Kwimba. The differences in number of peaks (mostly two) between the two experimental years could be due to the fact that different cassava varieties were used, that the sites were located in different places, and that possible weather differences occurred between the two years. The damage fluctuated over time and varieties, it started to increase in May through June and attained its peak in July and then declined in August or September. This was caused by the variations in environmental factors especially rainfall, temperature and relative humidity (Bonato *et al*., 1995; Gotoh *et al*., 2004; Teodoro *et al*., 2008).

Moreover, the resistant cassava varieties might have high leaf pubescence (Paters and Berry, 1980) and high canopy retention ability during the dry season (Nukenine *et al*., 1999). This indicated that the *M. tanajoa* damages have influence on different cassava varieties in the study areas (Nukenine *et al*., 2002). Among the nine varieties, Kyaka proved to be tolerant or resistant to the mite as it recorded the highest yield irrespective of the attack by the mite. The pest can attack cassava and may lead to yield reduction of about 21, 25 and 53% during a 3, 4 and 6 months attack i.e 73% for susceptible varieties and 15% for the resistant varieties (Lu *et al*., 2012). *Mononychellus tanajoa* severely make damage to cassava up to an estimate of 80% throughout the African continent (Toko *et al*., 1996; Mutisya *et al*., 2014). Similarly, the potential for yield loss or reduction by these pests is greater than the cyclical pests like hornworms which cause sporadic defoliation (Lu *et al*., 2012).

Furthermore, the leaf malformation and damage were found to be higher on crops at 3 and 6 months of age compared to the older ones but this was more pronounced during dry season periods. Ecologically the mite lives and feeds on young leaves and green stems and increases in population density during the transition period between wet and dry seasons (Yaninek, 1994). The responses of the cassava varieties at different ages have been mostly higher on younger plants compared to the older ones (9 months) and this has been sometimes fluctuating over time. These indicated that cassava green mites prefer young and tender plants which are succulent and nutritious compared to the fibrous older ones. This is in conformity to reports by other researchers such as ISC, (2016) that cassava plants aged 2-9 months are the most vulnerable to infestation.

4.6 Conclusion

Results of the study indicated that Liongo Kwimba recorded highest damage, leaf malformation and subsequently low yield compared to other varieties especially Kyaka and Meremeta. The least preferred and damaged by the pest, Kyaka variety recorded the highest yield. The leaf damage and malformation by *M. tanajoa* varied in both years. The highest leaf damage and malformation were recorded in June to August and lowest in March to May which with fluctuations among varieties over time in both years. Therefore, cassava varieties had differed in response to *M. tanajoa* attack due to their inherent characteristics. The variation in yield was not only influenced by variety characteristics but also other factors particularly the weather variables.

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CHAPTER FIVE

5.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

5.1 General Conclusions

Based on the findings, it was concluded that *M. tanajoa* was present in all cassava growing areas of the country and most of the grown varieties succumbs to the pest. Moreover, *M. tanajoa* counts were varied with the Lake and Southern zones recording the highest counts compared to the Eastern zone. The assessed cassava varieties had influenced *M. tanajoa* counts while cropping systems had no effect on insect counts in both 2015 and 2016. The relationship among the environmental variables, rainfall and temperature had negatively influenced *M. tanajoa* counts in 2015 while in July 2016 only rainfall was negatively correlated to *M. tanajoa*. The survival, perpetuation and distribution of *M. tanajoa* were attributed to the differences in varietal preference, crop age and weather variables.

The findings from the field experiments suggested that the trend in the occurrence of *M. tanajoa* had limited influence by locations. Almost all the tested cassava varieties sustained great counts of *M. tanajoa* and were susceptible while Kyaka and Meremeta varieties were resistant. The driest periods of the study had the highest *M. tanajoa* counts in both years. Higher counts were observed on young cassava plants compared to those with older foliage. Rainfall had negatively while temperature positively affected the survival, perpetuation of and subsequent damages by *M. tanajoa* in both years.

Conclusively, the responses of cassava varieties to *M. tanajoa* had indicated that Liongo Kwimba recorded highest damage, leaf malformation and subsequently low yield compared to other varieties especially Kyaka and Meremeta. The least preferred and damaged by the pest, Kyaka variety recorded the highest yield (43.235 ton/ha). Leaf damage and malformation were higher in 2016 compared to 2015 while the highest leaf damage and malformation were recorded in during the dry seasons with varied fluctuations among varieties in the rest on the months. The environmental and weather influence on the *M. tanajoa* counts and damages were varied across sites with rainfall and maximum temperature affecting the pest negatively while relative humidity and minimum temperature promoted the pest survival and perpetuation.

5.2 Recommendations

To increase cassava productivity in Tanzania, the following recommendations are made: There is an urgent need for researchers and extension specialists to come up with modalities of promoting some of the local cassava varieties that have shown characteristic sign of susceptibility or most preferred by the CGM with the tolerant or resistant ones in each of the agro-ecological zones. There is also need to investigate about the mechanism for the key causes of the tolerance or non-preference and vice versa on some varieties (especially Kyaka and Mrerema) by *M. tanajoa*. Therefore, promotion of these varieties (Kyaka and Mrerema) across the country will be imperative for improved cassava productivity in Tanzania.

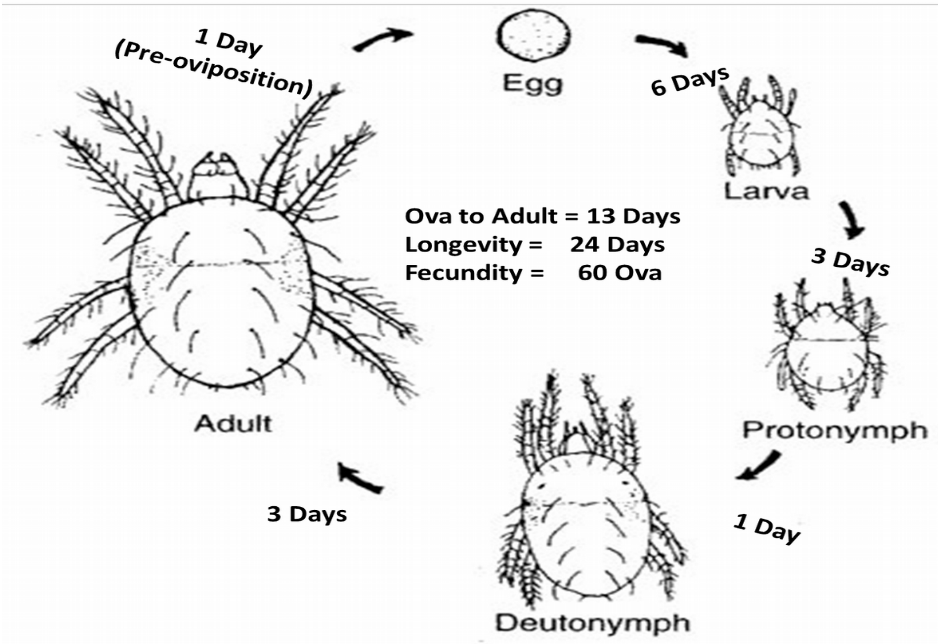
The relationship between CGM damage and loss of foliar components has to be explored. It is also pertinent to manipulate planting season by early planting before the favourable period of growth and perpetuation of *M. tanajoa* in the study areas and beyond. Further studies on the impact of *M. tanajoa* on cassava diseases inclusive of cassava mosaic disease and cassava brown streak disease in Tanzania is crucial. The study findings suggests that concerted effort should be employed through integrated pest management (IPM) strategies to overcome the negative effects of *M. tanajoa* on yield and livelihood of cassava growers in the country and the sub-Saharan Africa at large. Moreover, understanding of the strain diversity of *M. tanajoa* and whether the loss of foliar from the cassava crop is due to injury and subsequent damage by *M. tanajoa* or due to hypersensitivity reaction to the pests' damage or draught stress.

APPENDICES

Appendix 1.1: Picture of an adult female *Mononychellus tanajoa* and its egg

Source: SIC, 2015

Appendix 1.2: Egg to adult cycle of *Mononychellus tanajoa*



Source: Modified from Yaninek *et al.* (1989).

Appendix 1.3: Table of the Introduction Trend of *Mononychellus tanajoa* in Africa

Introduced From	Introduced To	Year	Reason	Introduced By	Establishment in Wild Through		Reference	Notes
					Natural Reproduction	Continuous Restocking		
South America	Uganda	1971	Crop Production (Pathway Cause)	Accidently (Unknown)	Yes	No	Nyiira, 1972; Yeninek & Herren, 1988	Found near Kampala
Uganda	Tanzania	1973	Crop Production (Pathway Cause)		Yes	No	Yeninek, *et al*., 1989b	Rate of spread 970 km/Year
Uganda	Congo	1975	Crop Production (Pathway Cause)		Yes	No	Yeninek, *et al*., 1989b	Rate of spread 1600 km/Year
Congo	Nigeria	1979	Crop Production (Pathway Cause)		Yes	No	Yeninek, *et al*., 1989b	Rate of spread 825 km/Year

Source: SIC, 2016

Appendix 2.1: Title and abstract of a published paper from objective 1 of the study

Archives of Current Research International

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Spatial and Temporal Distribution of Cassava Green Mite, *Mononychellus tanajoa* Bonder (*Acarina*: *Tetranychidae*) in Tanzania

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ABSTRACT

Two diagnostic surveys were conducted during the 2015 and 2016 growing seasons in three major cassava growing zones of Tanzania. The studies aimed at establishing the spatial and temporal distribution of *M. tanajoa* on commonly grown commercial cassava varieties across seasons and local landraces in Tanzania. A total of 2,700 plants in 90 fields were assessed in nine districts of which five fields were in the Lake zone and two districts in each of the Southern and Eastern zones. Results indicated that the distribution of *M. tanajoa* significantly *(P = .05)* differed across seasons, Southern and Lake zones were statistically similar and higher in *M. tanajoa* population than the Eastern zone. Crop age, altitude and cassava varieties significantly *(P = .05)* influenced the population of *M. tanajoa* while crop mixture (inter cropping) had no significant effect in both seasons. The relationship among the environmental variables and population distribution of *M. tanajoa* were significant *(P = .05)*.Variations in *M. tanajoa* population within and between seasons and locations were due to differences in the cassava varieties and the environment. The survival, perpetuation and distribution of *M. tanajoa* were attributed to the crop age, suitability of the variety and intensity of cassava cultivation.

Keywords: [Cassava Green Mite, Spatial, Temporal, Distribution, Cassava varieties, Tanzania.]

Appendix 2.2: Table of the raw weather data of the surveyed areas in Tanzania

ZONE	PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT
2015										
LAKE ZONE	Rainfall	45.8	36.4	62.60	12.60	50.20	4.80	0.00	0.00	54.2
	Temperature	27.4	29.8	29.0	29.8	26.3	28.4	27.8	28.9	29.6
	Relative Humidity	70.0	66.0	58.0	78.0	64.5	62.0	51.5	48.5	55.0
SOUTHERN ZONE	Rainfall	9.58	3.50	8.60	2.80	3.30	0.50	0.10	0.00	0.11
	Temperature	29.8	31.2	31.0	31.7	30.7	30.6	30.4	30.9	30.33
	Relative Humidity	24.0	71.6	77.9	75.6	71.0	61.2	53.5	53.3	52.3
EASTERN ZONE	Rainfall	75.9	10.4	221.1	195.1	256.6	5.80	0.90	6.40	26.3
	Temperature	31.5	33.9	33.0	31.9	29.5	29.6	29.9	30.6	30.6
	Relative Humidity	67.6	70.0	68.8	75.0	79.0	73.5	61.5	62.5	63.0
2016										
LAKE ZONE	Rainfall	4.13	0.78	2.88	6.24	0.89	0.40	0.00	3.50	9.70
	Temperature	28.1	30.3	31.6	29.7	29.5	29.8	30.5	31.3	32.0
	Relative Humidity	52.0	50.0	44.0	52.0	47.0	46.0	16.0	30.0	35.0
SOUTHERN ZONE	Rainfall	4.79	6.54	3.05	3.09	0.01	0.19	0.00	0.00	0.22
	Temperature	30.5	31.1	31.3	30.2	30.7	29.8	31.0	30.2	30.1
	Relative Humidity	47.8	71.3	71.0	67.0	63.4	56.6	54.5	53.9	60.1
EASTERN ZONE	Rainfall	113.2	76.2	42.2	326.0	0.50	3.00	5.30	6.60	17.90
	Temperature	33.4	32.5	34.6	30.9	30.9	30.7	30.4	30.6	30.5
	Relative Humidity	67.5	70.0	68.8	81.0	67.0	63.0	62.0	63.0	63.0

Key: The shaded columns shows data used for the regression analysis

Appendix 3.1: Title and abstract of a published paper from objective 2 of the study

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Weather Variability Influence on Occurrence and Damages of *Mononychellus tanajoa* Bonder (*Acarina*: *Tetranychidae*) on Selected Cassava Varieties in the Lake Zone, Tanzania

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ABSTRACT

A study was conducted in the Lake Zone, the leading cassava producing Zone in Tanzania during the 2015 and 2016 dry seasons. It aimed at establishing the occurrence of Cassava green mites (CGM), *M. tanajoa* and the influence of the weather variables on the pest's damage on commonly grown cassava varieties. The experiments were laid out in a Split plot design with varieties as sub plots and locations as main plots. The three locations were; Ukiruguru, Ng'ombe and Kishiri sites the former two being in Misungwi and one later in Kwimba districts respectively. Infestation with *M. tanajoa* was allowed to occur naturally. Results suggested that mites population and damage varied significantly ($P<0.05$) among varieties, data collection dates and locations in both years. Generally, Kwimba in 2015 and Ukiruguru in 2016 recorded the highest population of *M. tanajoa* while Ukiruguru had the lowest counts. The highest root yield was recorded at Ukiriguru in both seasons. Of the test varieties Liongo Kwimba, Naliendele, Suma and Namikonga were comparatively the most susceptible. Rainfall, relative humidity and temperatures contributed either positively or negatively to the survival, perpetuation of and damage by *M. tanajoa* in both seasons.

Keywords: Varieties, Cassava, Population, Damage, Dynamics and *M. tanajoa*

Appendix 3.2: **Title and abstract of accepted (In press) paper from objective 2 of the study**

Asian Journal of Advances in Agricultural Research

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Seasonal Dynamics and Damages of *Mononychellus tanajoa* Bondar (Acari: Tetranychidae) on Commercial Cassava Varieties in Mwanza Region, Lake Zone,Tanzania

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ABSTRACT

Two year studies were conducted to determine the responses of 9 commercial and local cassava varieties to *M. tanajoa* and the environment during the 2014/2015 and 2015/2016 wet and dry seasons at Ukiruguru in Mwanza region of the Lake Zone, Tanzania. The experiments were conducted at Lake Zone Agricultural Research and Development Institute, Ukiruguru. These were laid out in a Randomized Complete Block Design (RCBD) with three replications, making a total of twenty seven plots allocated to a plot size of 36m2 with 1m path between plots and 2m between blocks. One stem cutting (30cm long) was planted at a spacing of 1x1m within and between rows giving a total of 10,000 plant population ha-1. This was allowed under natural infestation by the mites. Results revealed that the population and damage were higher in 2016 while leaf malformation and mites incidence were statistically greater in 2015. Cassava varieties were heavily infested and damaged at lower age range (3 and 6 months) within and between the two seasons. Among the crop varieties, Liongo Kwimba recorded higher infestation and suffered most in leaf damage and malformation. Kyaka cassava variety was found to performed better in yield despite the attack by the mites while Liongo Kwimba recorded the lowest yield. The regression analysis predicted mostly negative relationships among the weather variables and the population, damage and incidence of *M. tanajoa*. Therefore, farmers at Ukiruguru could be encouraged to plant Kyaka variety for increased yield while Liongo Kwimba should be improved especially by breeding and molecular researches. More so, there is need to manipulate planting season by early planting before the favorable period of growth and perpetuation of *M. tanajoa*.

Keywords: [Occurrence, Kyaka cassava variety, Liongo Kwimba, Cassava green mite, Incidence and Tanzania]

Appendix 4.1: **Title and abstract of a published paper from objective 3 of the study**

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Response of Some Cassava Varieties to *Mononychellus tanajoa* Bondar. (Tetrachynidae: Acarina) Infestation in the Lake Zone, Tanzania

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ABSTRACT

The study was aimed to determine the responses of 9 commercial and local cassava varieties to *M. tanajoa* and the environment in two different seasons (2014/2015, wet and dry). in the lake Zone. This was laid out in a Split plot design with varieties as sub plots and locations as main plots. Three field trials were conducted at three different locations, Ukiruguru (Latitude 020 43.156' S, Longitude 0330 01.431' E and elevation of 4000m above sea level) N'gombe (Latitude 020 45.743' S, Longitude 0330 01.838' E and elevation 3888m above sea level) and Kishiri (Latitude 020 48.694' S, Longitude 0330 22.161' E and elevation 4023m above sea level) villages of Kwimba and Misungwi districts of Mwanza respectively. In each location, the 9 varieties were planted and randomized into nine plots using Split plot Design with location as main and varieties as sub plots, these were replicated three times making a total of twenty seven plots. The treatments were allocated to a plot size of $36m^2$ with 1m path (boarder) between plots and 2m between blocks. One stem cutting (30cm long) was planted at a spacing of 1x1m within and between rows giving a total of 10,000 plant population ha^{-1}. This was allowed under natural infestation by the mites. The results indicated that the mites population and damage generally varied significantly (P= 0.05) among varieties, sampling dates and locations. In general, Kwimba recorded the highest population number of *M. tanajoa* while Ukiruguru had the highest root yield and number. The study shows that Kyaka appeared to be tolerant/resistance to cassava green mite while Liongo Kwimba, Naliendele, Suma and Namikonga were found to be most susceptible respectively. Therefore, cassava varietal resistance has a significant effect on the population dynamics and severity of *M. tanajoa* in the Lake Zone, Tanzania.

Keywords: Varietal, Environmental Responses, Dynamics and *M. tanajoa*

Appendix 4.2: **Title and abstract of a draft paper (Under review) from objective 3 of the study**

IMPACTS OF CASSAVA GREEN MITE (*Mononychellus tanajoa*, Bondar (Acarina: Tetranychidae)) INFESTATION ON SELECTED CASSAVA VARIETIES IN THE LAKE ZONE, TANZANIA

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Abstract

Field experiments were conducted at three locations in Mwanza region in the Lake Zone of Tanzania namely; Ukiruguru, N'gombe and Kishiri villages. Studies aimed at evaluating the impacts of *M. tanajoa* on nine commercial and popular local cassava varieties during 2014/2015 and 2015/2016 wet and dry seasons. These were laid in a Randomized Complete Block Design (RCBD) in three replications, making a total of twenty seven plots. Each treatment was allocated to a plot size of $36m^2$, separation distance of 1m and 2m path between plots and blocks was maintained. One stem cutting (30cm long) was planted at a spacing of 1x1m within and between rows giving a total of 10000 plant population ha^{-1}, infestation with *M. tanajoa* was naturally. The results revealed that all the tested cassava varieties variably responded to mite damages with subsequent leaf malformation ($P \leq 0.001$). The variations were significant within and between seasons. Generally, the leaf damage and leaf malformation were higher in 2016 compared to 2015. Cassava varieties, Kyaka and Suma recorded the least damages while Liongo Kwimba was the most damaged among all the varieties tested. Despite the varied response to damages the tested yield components (root number and root weight) did not vary significantly although var., Kyaka and Meremeta recorded relatively higher yield. Therefore, efforts should be geared at breeding for tolerance to *M. tanajoa* to improve the adapted local varieties especially Liongo Kwimba and Kyaka. The results corroborate the preliminary results on responses of the cassava varieties in the first year.

Keywords: *M. tanajoa,* Cassava varieties, Damage, Leaf malformation, Responses.