SURVEY AND MANAGEMENT OF CASSAVA MOSAIC DISEASE IN WESTERN KENYA WITH EMPHASIS ON SIAYA DISTRICT

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BY

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A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN HORTICULTURE OF EGERTON UNIVERSITY

NJORO, KENYA

2006

2007/72836

DECLARATION

This thesis is my original work and has not been presented for the award of any other degree elsewhere.

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RECOMMENDATION

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DEDICATION

To my parents Samuel Ochiel and Hannah Awuor for teaching me the meaning of unconditional love and for being such a great support. To James Legg and Dorcas Isutsa for believing in the beauty of my M.Sc. dream and helping me achieve it.

ACKNOWLEDGEMENT

I would like to thank my family for all their encouragement and love in the course of this study. My sincere appreciation to my supervisors Dr. J. P. Legg, Prof. D. K. Isutsa and Dr. A. W. Kamau for their whole-hearted guidance, commitment and support during the course of this study. My sincere gratitude to Prof. J. M. Thresh for reading the manuscript and for his valuable comments and constructive criticism. The USAID Office for Foreign Disaster Assistance (OFDA) CMD pandemic mitigation project through the International Institute of Tropical Agriculture, Eastern and Southern Africa Regional Centre (IITA-ESARC) funded the research work for which I am grateful. The contribution and support of the Kenya Agricultural Research Institute, Kakamega is acknowledged.

The dedicated contribution of A. Ouma, J. Otieno and the entire "Ugenya cassava team" in maintenance of the field trials is highly appreciated. The cooperation and commitment of my farmers: B. Muga, O. Makalama, J. Oyombe, M. Ofwona, M. Ogot, O. Ahenda, J. Aloo, A. Nyaoro and S. Obura together with families are appreciated. P. Ouma for providing transport, O. Onyango and F. Ger for the sacrifice of driving during the Siaya surveys and field trials. The technical assistance of R. Obonyo and G. Okao-Okuja is acknowledged. The contribution of B. Owor, M. Otim, E. Byamukama, P. Asiimwe, P. Sseruwagi, M. Kiryewala, F. Atugonza and other colleagues at IITA-ESARC is appreciated. The support of H. Obiero, M. Akhwale, C. Lwanga, S. Ajanga, E. Isindu, J. Mpapale, M. Mudheheri and other colleagues at KARI-Kakamega, especially in the western Kenya survey work, is also acknowledged.

The patience and support of my course mates R. K'Oboge, T. Odongo, G. Opetu, N. Korir, J. Ngure and other colleagues and lecturers at Egerton University is appreciated. Finally, thanks to A. Shahasi, R. Irungu, G. Mwangome, M. Obura, C. Obura, H. Okema, B. Bodo, J. Owinyo, J. Kikuyu, A. Murunga, C. Barasa, S. Nantongo, N. Okello and the many special friends and relatives who have shown me love and support in so many practical ways that have made it possible to see this work come to a logical conclusion. I am indebted to you.

ABSTRACT

Cassava mosaic disease (CMD), caused by cassava mosaic geminiviruses (CMGs) is the most important constraint to cassava production in East Africa. From 1995, a severe form of the disease spread from Uganda into western Kenya, leading to total crop loss. In spite of much research effort, CMD continues to cause losses. The potential of cultural methods in the management of CMD is a crucial unanswered question. The current research had five objectives, namely: (1) establishing the current status of the CMD epidemic in western Kenya, (2) identifying CMGs present in Siaya district, (3) comparing the relative effectiveness of cultural methods and resistant varieties in managing CMD, (4) determining incidence and severity of CMD in Siaya district, and (5) assessing growth and yield loss in healthy or diseased planting materials. The first two objectives were achieved through a survey and polymerase chain reactions for virus diagnosis; the third objective through a factorial experiment with four varieties and four cultural methods, replicated in two divisions; the fourth objective through a completely randomized design, with two varieties and four divisions; and the fifth through a split plot experiment with three varieties and two disease conditions, replicated three times. All studies, except the fourth one were repeated over two seasons. Variables surveyed or measured included: socio-economic factors, varieties grown, virus type, CMD severity and incidence, adult whiteflies, growth parameters and cassava yield. Data were subjected to appropriate analyses. Results showed that CMD epidemic has continued to spread southwards and has been a major constraint to cassava production in western Kenya. East African Cassava Mosaic Virus-Uganda strain was the most frequently occurring CMG in all districts of western Kenya, except West Pokot during 2002. In farmers' fields, 75% of the incidence was a result of cutting infection. Improved CMD-resistant varieties were most effective management strategy and exhibited low CMD incidence. Incidence of CMD in Siaya, a post-epidemic area, was low-to-moderate (4% to 68%), while severity was moderate. Choice of CMD symptom-free planting material of susceptible varieties was beneficial and gave yields that compared favourably with those of improved material. Yield loss due to CMD in susceptible varieties exceeded 60%, while in CMD-resistant varieties it was negligible. Thus CMD-resistant varieties and choice of disease-free planting materials of CMD-susceptible landraces holds great potential for success. Efforts in western Kenya should now be geared towards educating and enabling farmers to practice integrated approaches in management of CMD.

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LIST OF ACRONYMS

ACMV	=>	*African cassava mosaic virus*
CGM	=>	Cassava green mite
CMD	=>	Cassava mosaic disease
CMGs	=>	Cassava mosaic geminiviruses
EACMV	=>	*East African cassava mosaic virus*
EACMV-UG	=>	*East African cassava mosaic virus*–Uganda
FAO	=>	Food and Agriculture Organisation
GPS	=>	Global positioning system
IITA	=>	International Institute of Tropical Agriculture
MAP	=>	Months after planting
PCR	=>	Polymerase chain reaction
REN	=>	Red-eyed nymph
WAP	=>	Weeks after planting

CHAPTER ONE

INTRODUCTION

1.1. Origin, Ecology and Importance of Cassava

The Amazon region in South America is thought to be the centre of domestication of cassava (*Manihot esculenta* Crantz). The Portuguese brought cassava to Africa in the 16th century; reaching the west coast of Africa via the Gulf of Benin and the river Congo, the east coast via the islands of Reunion, Madagascar and Zanzibar (Jennings, 1976; Jones, 1989). In East Africa, Stanley first reported cassava around Lake Victoria in 1878; it may have reached there along trade routes. The crop was, however, not established in Uganda and western Kenya until the 19th century. Cassava is currently grown in all African countries south of the Sahara desert and north of river Limpopo (Hillocks, 2002).

Cassava is a shrubby dicotyledonous plant in the family Euphorbiaceae (Purseglove, 1968), and the genus *Manihot*, which commonly produce latex and cyanogenic glucosides. Cassava grows in a wide range of ecological conditions, but is perhaps best adapted to the zone within latitudes 30° North and South of the equator. Since cassava is a short-day plant of tropical lowlands, the highest yield of roots occurs in these regions. Cassava has enormous ability to adapt successfully, and can grow at elevations of up to 2000 m above sea level. The optimum temperature supporting growth ranges from 17°C to 25°C, whereas the average annual temperature is about 20°C (Cock, 1979). Cassava requires a fairly well distributed rainfall of about 1000 to 1500 mm for optimum growth. The plants prefer a soil pH of 4 to 9 and a lot of water, but not waterlogging (Nweke et al., 2002).

Cassava crop is particularly important in marginal land where it grows with only limited labour and management. It is easy to grow, because it requires minimum land preparation and tolerates soil acidity, low soil fertility, erratic rainfall and drought, while giving economic yields. These are the attributes that make it appropriate for resource-poor farmers in many farming systems in Africa (Howler et al., 2001).

Cassava is a major food and industrial crop in Africa, Asia and Latin America. Surveys done by Collaborative Study of Cassava in Africa (COSCA) in selected African countries showed that cassava production in Africa has increased in the last century in response to famine, hunger and drought. The findings confirmed that cassava is planted as a key food-security crop (Nweke, 1994). Cassava is second to maize as Africa's most important staple crop in terms of

per capita calories consumed, but first in terms of total fresh weight production (Nweke et al., 2002). Cassava is second to maize as the most important energy-supplying and food-security crop in the lake basin region of Kenya. Western Kenya's yield accounted for almost two-thirds of the national production before the cassava mosaic disease pandemic. In the late 1990's the area under cassava was 100,000 ha, yielding 9.5 t/ha (FAO, 2003).

Cassava holds great promise for feeding Africa's expanding population, increasing farm income to reduce poverty and generating foreign exchange, as an industrial crop (Nweke et al., 2002). Cassava can be processed into animal feed, starch, and starch-based products. Currently in Africa, it is mainly sold as fresh tubers or leaves for consumption (Howler et al., 2001). Roots of 'sweet' cassava varieties are either eaten raw, roasted on an open fire, boiled in water, or fried in oil (Grace, 1977). 'Bitter' cassava varieties are used to make starch and flour — a most widespread food product. Flour is generally eaten as a thick paste with soups and stews such as '*gari*' and '*tapioca*'. The paste is obtained by mixing cassava flour in hot water. Cassava flours are also used to prepare deep-fried savoury or sweet cakes (Dixon, 1999).

1.2. Statement of the Problem

Cassava has the potential of being transformed from a low-yielding, famine-reserve crop to a high-yielding cash crop. However, it has long been marginalized in food policy debates, because of stigma burden. The stigma arises from cassava being considered an inferior crop for the rural poor (Nweke et al., 2002). The constraints hampering its production include poor access to good quality planting material, lack of well-adapted varieties, poor agronomic and post-harvest handling practices, lack of effective extension services to disseminate new technologies, weak marketing strategies and hence poor price incentives (IITA, 1990; Hillocks, 2002), diseases and pests. Major diseases include cassava mosaic disease, cassava brown streak disease, cassava bacterial blight [*Xanthomonas axonopodis* pv. *manihotis* (Berthet and Bondar)], cassava anthracnose disease [*Colletotrichum gloeosporoides* fs. *manihotis* (Penz.) Penz. & Sacc], cassava brown leaf spot [*Cercosporidium henningsii* (Allesch)], cassava white leaf spot [*Phaeramularia manihotis* (F. Stevens & Solheim) M. B. Ellis] and blight leaf spot [*Cercospora vicosae* Muller and Chupp]. Major pests include cassava green mite [*Mononychellus tanajoa* (Bondar)] and cassava mealy bug [*Phenacoccus manihoti* Matt.-Ferr] that were both introduced to Africa in the 1970's. The pests have both been effectively managed using biological control agents such as

phytoseid mite (*Typhodromalus aripo* DeLeon) against cassava green mite, and parasitic wasp (*Anagyrus lopezi* De De Santis) against cassava mealy bug (Sakala et al., 1998). Other pests include termites, white scale [*Pseodalacapis pentagona* (Targioni-Tozzetti)], variegated grasshopper [*Zonocerus variegatus* (L.)], elegant grasshopper [*Dichromorpha elegans* (Thunberg)], nematodes (*Meloidogyne* spp.), vertebrates and weeds.

Cassava mosaic disease (CMD) is the major biotic constraint limiting cassava production in all main cassava-producing areas of Africa (Thresh et al., 1994b). It is caused by cassava mosaic geminiviruses (CMG's) in the family *Geminiviridae* and genus *Begomovirus*. The viruses are transmitted by the whitefly (*Bemisia tabaci*), and disseminated through infected cuttings used as vegetative planting materials. Epidemiological experiments from coastal and western Kenya in the 1970's concluded that infection pressure was generally low, except in wetter parts of coastal Kenya where cassava is cultivated intensively (Bock and Woods, 1983). However, a pandemic caused by the *East African cassava mosaic virus*–Uganda (EACMV-UG) has spread into western Kenya from Uganda (Gibson, 1996; Legg, 1999). As a result, cassava production has declined drastically since 1995; some districts have experienced almost total crop failure, prompting farmers to abandon production, especially of highly susceptible varieties such as Adhiambolera (Obiero et al., 2003).

The expanding CMD pandemic in western Kenya where there was widespread use of susceptible varieties has devastated cassava growth and production. Without effective management, CMD will continue to cause serious devastation, thereby threaten food security and inhibit poverty alleviation in the region. Consequently, the current research was formulated to search for effective management strategies.

1.3. Justification of the Research

Cassava mosaic virus is the most important pathogen of cassava (Geddes, 1990); its disease has received more attention than other diseases of African food crops (Thresh, 1991). About 27% of Kenya's population live in western Kenya where maize is the staple food crop and cassava is a food-security crop. The area under cassava, the prevalence of CMD, and varieties grown can change quickly and substantially. This is apparent from recent developments in Uganda and western Kenya, resulting in dramatic shifts from a benign to an epidemic, and finally to an endemic situation (Otim-Nape et al., 1996; Thresh et al., 1997). Field surveys need

to be conducted to monitor the spread of CMD and establish its current status. Resulting information will offer a good basis for formulating effective management measures and guidelines that decision-makers and budget holders could use when allocating resources for disease control (Sseruwagi et al., 2004a).

In western Kenya, following the precedent set in Uganda, management efforts have focused mainly on multiplication and dissemination to farmers of CMD-resistant varieties. The area under improved cassava is now approximately 14,000 ha. Studies in 10 districts in Western and Nyanza provinces indicate that although all farmers are interested in improved varieties only 10% have access to these varieties (Obiero et al., 2003). There are areas where existing susceptible varieties are being wiped out and there is a threat to other areas not yet affected by the pandemic. Other pests such as cassava green mite heavily attack some newly introduced resistant varieties, thereby making the varieties not always suitable for all areas. These scenarios increase the need to continuously multiply and distribute CMD-resistant varieties; however, the long-term nature of cassava presents logistical difficulties in attaining this goal.

Recent studies have implicated cyanide in the resistance of cassava to pests like CGM and in reduction of herbivory; thus, subsistence farmers in sub-Saharan Africa may rely on the toxicity of cyanogens to protect their crops (Sayre, 2000). Hydrocyanic acid (HCN) forms in cassava when endogenous enzymes hydrolyse linamarin and lotaustralin cyanogenic glucosides. The high HCN level, together with other factors, is responsible for the bitterness in roots of some CMD-resistant varieties (Belloti et al., 1997). Breeding programmes normally target development of low HCN varieties; some of these varieties exhibit inferior quality when compared to farmers' varieties, either because of the low HCN or poor organoleptic properties.

Thus, there is need to investigate alternative means of management using landraces already available to enhance development of a good integrated management component for CMD (Legg et al., 2000; Otim-Nape et al., 2000). Integration includes use of phytosanitation practices such as planting CMD-free propagules and roguing of any plants that appear diseased (Thresh et al., 1998a). Demonstration that sanitation is unwarranted when varieties are suitably resistant, and development of protocols for producing "clean" and vigorous cuttings for low to moderately resistant cassava varieties would greatly facilitate extension work. This is so because there is insufficient knowledge concerning the appropriate criteria for choosing clean cuttings, and the optimal conditions for maintenance of plants (Thresh, 2003).

1.4. Objectives

1.4.1. The general objective of this study was to develop tactics for management of cassava mosaic disease in western Kenya, using Siaya District as a case study. The long-term aims were three-fold: develop simple decision-making guidelines (recommendations) for management of CMD; increase food-security and accrued income; and alleviate poverty, particularly among resource-poor farmers.

1.4.2. The specific objectives were as follows:

(1) To survey and determine the current status of the CMD epidemic in western Kenya.

(2) To identify the CMGs present in different parts of Siaya district.

(3) To assess effectiveness of phytosanitation and resistant varieties in managing CMD.

(4) To determine the incidence, severity, and inoculum pressure of CMD in Siaya District.

(5) To assess growth and loss of yield due to cassava mosaic disease in local and improved varieties planted using initially healthy or diseased propagules.

1.5. Hypotheses

(1) The CMD epidemic has continued to expand its range further southwards in western Kenya.

(2) Different CMGs infect different varieties in different disease-spread areas of Siaya.

(3) Phytosanitation is relatively effective compared to resistant varieties as an appropriate CMD management approach, under given levels of CMD inoculum pressure and varietal sensitivity.

(4) There is a range of response to CMD that varies with variety and inoculum pressure in different locations in Siaya district.

(5) There are substantial but variable losses due to CMD in selected cassava varieties.

CHAPTER TWO
LITERATURE REVIEW

2.1. Cassava Mosaic Disease

Cassava mosaic disease is the most economically important viral disease of cassava in Africa, India and Sri Lanka (Calvert and Thresh, 2002). Warburg first reported it in 1894 in Tanzania as 'Krauselkrankheit' (Storey and Nichols, 1938). The disease has since then been recorded in all the cassava-growing areas of Africa including the offshore islands of Cape Verde, Zanzibar, Madagascar, and Seychelles (Calvert and Thresh, 2002). The disease is caused by cassava mosaic geminiviruses that are disseminated through infected cassava cuttings and transmitted by whiteflies (Fargette et al., 1988). First demonstration of transmission by the vector known at the time as *Bemisia mosaicivectura* was reported in Congo (Kufferath and Ghesquiere, 1932; Storey and Nichols, 1938). In Kenya, first transmission tests were conducted in 1981, using the same earlier whitefly species (Seif, 1981). The whitefly was subsequently renamed *B. tabaci*; this is the name used in all later studies.

The first species of CMG's to be distinguished in East Africa are *African cassava mosaic virus* (ACMV), and *East African cassava mosaic virus* (EACMV); they were initially considered to have separate, largely non-overlapping distributions (Swanson and Harrison, 1994). Earlier work in the 1970's and 1980's showed that planting infected cuttings was the most important epidemiological factor influencing the occurrence of CMD in coastal and western Kenya. The symptoms were moderate to mild and the infection pressure was relatively low with an overall incidence in Kenya of about 20% (Bock, 1983, 1994). A recombinant strain called *East African cassava mosaic virus*–Uganda (EACMV-UG) (Deng et al., 1997), or the Uganda variant (Zhou et al., 1997) causes more severe symptoms than the ACMV that occurred previously. *East African cassava mosaic virus*–Uganda is associated with the current CMD pandemic in East and Central Africa (Harrison et al., 1997; Legg, 1999). Among the pandemics known to have affected Africa at different times and places in the 20th century, the EACMV-UG pandemic is the worst and most fully documented (Calvert and Thresh, 2002).

Severe CMD symptoms of the type now caused by EACMV-UG were first recorded in northeastern Uganda in 1988 (Otim-Nape, 1988). Subsequently, the spread of EACMV-UG was shown to be associated with expansion of the pandemic (Harrison et al., 1997). In 1996, the first report of the severe form of CMD in western Kenya was made from a location near the border

with Uganda (Gibson, 1996). The area affected expanded rapidly to encompass the entire Western Province and the northern part of Nyanza Province between 1995 and 1998, resulting in a high (80%) disease incidence, mainly attributed to whitefly infection, and moderate to severe symptoms (Legg et al., 1999b). In East Africa the response of ordinary farmers to the disease has been either to abandon or drastically reduce cassava cultivation (Otim-Nape et al., 2000).

The general characteristic symptoms of CMD include misshapen or twisted leaves, reduced leaf size, irregular mosaic patterns, and yellow-green chlorosis of the laminae. In severe cases, plants become stunted and young leaves abscise (Calvert and Thresh, 2002). Characteristic leaf symptoms vary in type and severity, but appear as 'green mosaic', or 'yellow mosaic'. Leaves affected by green mosaic bear normal and light-green tissue not associated with obvious decrease in leaf area, leaf number, plant size, or yield. Yellow mosaic obviously shows contrasting normal-green and yellow tissue. Chlorotic areas may expand less than adjacent tissue, resulting in distortion of leaflets, severe chlorosis, and obvious decrease in growth and yield. Other factors causing similar leaf damage include drought, waterlogging, mineral deficiency (especially zinc), infestation by cassava green mite, as well as cassava mealy bug (Calvert and Thresh, 2002).

Spread of CMD is influenced by sensitivity of the variety grown, inoculum pressure and nature of systemicity in infected plants (Lwole, 2000). Varieties differ greatly in their response to infection. Some varieties become more severely affected than others (Fargette etal., 1996). There is a general relationship between CMD symptom severity and reduction in plant performance (Fauquet and Fargette, 1990). Cassava mosaic disease causes various effects on growth and yield, depending on the strain of the infecting virus. Some virus strains or combinations cause more severe symptoms and reduce growth and yield more than others. Symptoms are most severe if EACMV-UG occurs together with ACMV in a mixed infection (Harrison et al., 1997). The effect is similar for mixed ACMV and *East African cassava mosaic Cameroon virus* infections (Fondong et al., 2000). Cassava mosaic disease determines performance and sustainability of varieties by influencing the number, viability and growth of stem cuttings used for propagation (Calvert and Thresh, 2002). Plants grown using infected cuttings suffer more severely than those of the same variety when infected at a later stage by whiteflies. Thus, plants affected at later growth stages sustain little or no damage (Fargette et al., 1988).

The three types of epidemiological situations distinguishable in Africa are referred to as epidemic, endemic, and benign (Thresh et al., 1997). Two types of studies have been carried out for CMD yield loss effects. 'Type A' consisted of formal replicated trials established with infected or healthy cuttings, and 'type B' using data from naturally infected plants, selected in experimental plantings or farmers' fields. A review by Thresh et al. (1994a) showed that pre-pandemic 'type A' experiments were carried out in Kenya using local varieties; comparisons were made between plant cuttings infected and not infected by ACMV (Seif, 1982). However, none of the experiments reported the magnitude of yield losses that are associated with CMD pandemic; the losses are estimated to range from 20% to 95% for individual susceptible varieties. Surveys conducted in three cassava-growing districts of Uganda showed yield reductions of up to 95%, depending on variety and severity of CMD symptoms (Otim-Nape et al., 1996; Otim-Nape et al., 1998).

2.2. *Bemisia tabaci*: Vector of Cassava Mosaic Geminiviruses

The whitefly, *Bemisia tabaci*, is a major pest of numerous crops worldwide affecting 586 plant species from 74 families (Greathead, 1986). It is an economically important pest, as a result of its extreme polyphagy and its role in virus transmission (Mound, 1963; Brown, 1994; Fishpool and Burban, 1994). It affects cassava plants by feeding on leaves, which may develop chlorosis; heavy feeding leads to growth of sooty moulds and reduced plant vigour (Byrne et al., 1990). On the other hand, it transmits more than 60 viruses (Crop Protection Compendium, 2002).

Bemisia tabaci is a member of the family Aleyrodidae and order Homoptera. During reproduction unmated females produce males, whereas mated females produce both males and females (Gerling, 1986). Males (0.8 mm) are shorter than females (1.0 mm) and have a narrower abdomen (Fishpool and Burban, 1994). Adults preferentially feed and oviposit on the youngest immature leaves (Fargette, 1985). Females lay elongate-ovoid eggs; the number of eggs laid varies for different populations and conditions (Gerling, 1986). Whiteflies develop through four nymphal instars; the first instar takes about five days in East Africa while the second and third instars take 2 to 3 days each, depending on temperature (Legg, 1995). Only the first instar (also called a crawler) is mobile. The second, third and fourth instars are shield-shaped, but differ in size. The fourth instar develops red eyes; this stage is commonly described as the pupa, or more accurately red-eyed nymph (REN) (VonArx et al., 1984). Egg laying to hatching takes 7 to 11

days, whereas first instar to adult-emergence takes 20 to 28 days; the durations depend on host species, temperature and humidity (Legg, 1994). Newly emerged adults have a yellow body and colourless wings, which gradually turn white (Byrne and Hadley, 1988).

Cultivated cassava is the only significant host of the cassava *B. tabaci* biotype (Burban et al., 1992; Legg, 1996). *Bemisia afer* (Priesner and Hosny) is also found in small numbers, mainly on the lower leaves of cassava, but there is currently no evidence to suggest that it transmits CMGs. During CMG transmission by *B. tabaci* adults, minimum and optimum periods are 3 hours and 5 hours, respectively, for acquisition; 3-4 hours and 6 hours, respectively, for the latent period; and 10 minutes and 3 hours, respectively, for inoculation. The whitefly remains viruliferous for 7 to 9 days. The virus is passed between larval instars during ecdysis (trans-tadial transmission), although there is no trans-ovarial transmission (Fishpool and Burban, 1994; Dubern, 1994).

Whitefly populations are affected by climatic factors, including particularly temperature, rainfall, humidity, and solar radiation (Horowitz, 1986). The CMD pandemic has been associated with unusually large population densities of the whitefly vector. Detailed studies of the 'front' of the expanding CMD epidemic revealed that the population of *B. tabaci* at and behind the front was significantly higher than that ahead of the front (Legg and Ogwal, 1998), and that a distinctive genotype cluster of *B. tabaci* was associated with the epidemic (Legg et al., 2002). Whitefly-borne infection is characterised by appearance of disease symptoms solely on the uppermost leaves; cutting-borne infection is characterised by appearance of disease symptoms on the lowermost leaves, as well as on either all or some of the upper leaves.

2.3. Integrated Management of Cassava Mosaic Disease

An outcome of the EACMV-UG associated pandemic and recognition of the merits of landraces is the increased research on various approaches that could be used to control CMD (Thresh and Otim-Nape, 1994; Thresh 2003). Zadocks and Schein (1979) described measures that decrease the initial amount of inoculum (X_0) from which spread occurs; these measures include phytosanitation and decrease of the rate of disease progression (r) through vector-control, cropping practices, mild strain protection, and host-plant resistance.

2.3.1. Vector control

Classical biological control approach is not possible for *B. tabaci*, which is indigenous to Africa. Pathogens, parasitoids and predators are the natural enemies used as agents to help in the biocontrol of whiteflies on other crops. Most records on natural enemies of *B. tabaci* are qualitative, whereas few are quantitative (Gerling, 1986). There are over 40 species of parasitoids in the family Aphelenidae, which are known to attack *B. tabaci* (Gerling et al., 2001). Studies carried out in Uganda identified and characterised the dominant parasitoids of the cassava whitefly as *Encarsia sophia* and *Eretmocerus mundus;* their population increases when whitefly population increases, although percent whiteflies parasitized decrease (Otim, 2003).

Insecticides are used in Asia, as well as in South and Central America to control whiteflies on cotton and vegetable crops, because of the high population densities and direct damage caused. Synergised pyrethroid sprays are primarily effective against adult whiteflies through contact action (Horowitz and Ishaaya, 1996). Efficacious synergised pyrethroids are presently registered for use in vegetables such as cauliflower (Palumbo and Coates, 1996), tomatoes and peppers (Stansly and Conner, 1995). In Sudan, chemicals have been used to effectively control whiteflies on cotton. However Dittrich et al. (1990) showed that whiteflies have developed resistance to insecticides, because of long-term exposure. In Africa, whitefly population densities on cassava are usually relatively low and physical damage is rarely observed, thereby not warranting use of insecticides. Another constraint facing insecticides is that cassava grows for 12 months and is considered a low-value subsistence crop; repeated spraying would be uneconomical. Besides, only a small proportion of farmers are able to afford insecticides, even if they were effective (Thresh and Otim-Nape, 1994). No records exist on use of chemicals to control cassava whiteflies in Africa, except for experimental purposes. In Africa, insecticides are ineffective, because they do not kill in-coming viruliferous whiteflies, which require brief feeding periods to transmit CMGs (Dubern, 1994).

2.3.2. Cropping practices

There is abundant evidence from a wide range of crops on the importance of decreasing the incidence of viral infection and the subsequent losses they cause through changing cropping practices before, at, or after planting (Thresh, 1982). Virus spread is facilitated by some practices and impeded by others. Farmers should adopt measures that are either beneficial or neutral in

their effects and abandon detrimental ones (Thresh, 2003). Various cropping practices tested to manage CMD include timing planting to decrease risk of infection, intercropping with non-host plants (Fondong et al., 2002), and spacing to achieve high plant populations that in turn decrease whitefly populations and hence CMG spread (Hilje et al., 2001). The benefit of close spacing in reducing the proportion of CMD-infected plants has been demonstrated in Ivory Coast (Fargette et al., 1990) and in subsequent studies in Uganda (Osiru et al., 1999; Egabu et al., 2002).

Varietal mixtures and intercropping are important in providing farmers with some degree of resilience and stability that contributes to reliable crop yields and avoids total failure (Smithson and Lenne, 1996). In Columbia, Gold (1995) showed a beneficial effect of reduced whiteflies and increased cassava yield after inter-cropping cassava with cowpea (*Vigna unguiculuta*). He suggested that this effect was partly a consequence of poor leaf production and aerial growth of the intercropped cassava. Sserubombwe et al. (2001) observed a decrease in the spread of CMD to a susceptible variety of cassava when grown together with resistant varieties. The potential of varietal mixtures and intercrops either as physical barriers, camouflage impairing early colonisation of cassava, or as competitors reducing the suitability of cassava for *B. tabaci* and its effects has received little attention; thus, there is scope for much additional research (Legg, 1994; Thresh, 2003).

2.3.3. Plant protection using mild strains

The ability of mild strains to protect plants from damaging effects of closely related virulent strains has been recognized; virologists extensively use this phenomenon to assess relationships between viruses and virus strains. Mild-strain protection has been used to successfully control *tomato mosaic virus* that was so prevalent and difficult to control by other means (Fulton, 1986). Single ACMV infections typically cause mild to moderate symptoms (Harrison et al., 1997); EACMV-UG causes mild to severe symptoms, which correspond to its mild and severe forms (Pita et al., 2001). *East African cassava mosaic virus*–Uganda can super-infect plants with ACMV, producing the most severe symptoms (Harrison et al., 1997). Research carried out in Uganda compared performance of initially CMD-free plants and plants infected with EACMV-UG under high inoculum pressure. Results revealed better performance of mildly diseased plants in comparison to initially healthy plants that later became severely affected during growth. This response was attributed to severe attack of initially healthy plants, as well as

the fact that the new strains infect initially healthy plants more readily than they do mildly diseased plants that are possibly protected against severe strains (Owor, 2002; Owor et al., 2004a).

2.3.4. Resistant-plant varieties

Genetic diversity is a feature of most crop species and has been exploited by agriculturists to increase crop productivity and avoid serious damaging effects of pathogens. Breeding, selection and adoption of genotypes that yield satisfactorily and avoid or in some way withstand virus damage are the processes through which resistant varieties are developed (Thresh, 2003). Deployment of resistant varieties has for long been considered the most effective and convenient way for large-scale and long-term control of viral diseases (Thresh and Otim-Nape, 1994). Consequently, the focus on CMD management has been on deployment of resistant varieties. The search for cassava cultivars with resistance to ACMV began in East Africa in the late 1920's and was very active in the 1930's and 1940's. Trials of cultivars and selections were done at Malindi in Kenya, Morogoro and Amani in Tanzania, Zanzibar, and elsewhere. Crosses were made at Amani between cassava and the tree species *M. glaziovii* Muell-Arg (ceara rubber) that is usually free of mosaic symptoms if it is growing strongly. An F1 hybrid of this cross was produced in 1937, followed by backcrossing and further selection. Clone 58308 is one of the CMD-resistant clones developed, although it yields poorly. This clone forms part of the genetic base for cassava improvement at IITA (Jennings, 1994).

When CMD became a serious problem in Madagascar in the 1920's to 1930's, consequences were severe, because there were no resistant varieties. Once resistant varieties were developed and widely accepted to manage CMD the situation reverted to benign (Cours et al., 1997). A similar trend occurred in the 1990's in Uganda and more recently in western Kenya (Teso, Bungoma and Busia districts), where there is considerable recovery in areas that were first attacked and in which CMD-resistant varieties were introduced to replace the vulnerable local genotypes grown previously (Otim-Nape et al., 2000; Obiero et al., 2003).

Resistance to CMD does not mean that plants are immune to infection; it, however, means that a low proportion of plants become infected and develop less conspicuous symptoms, when compared to susceptible ones (Thresh et al., 1998a). Symptoms in resistant varieties are restricted to certain shoots or branches and sometimes disappear as plants recover. Recovery

happens if an initially diseased plant that had shown symptoms produces symptomless shoots (Thresh et al., 1994c). Infection is less systemic in resistant varieties than in susceptible ones. Consequently, a proportion of cuttings may produce disease-free plants through reversion. Reversion describes the phenomenon by which symptom-free plants arise from cuttings derived from diseased plants (Fargette et al., 1994). Reversion and recovery are common characteristics of plant resistance (Rossel et al., 1988; Gibson and Otim-Nape, 1997; Colvin et al., 1998; Alicai et al., 1999).

Resistant varieties contain a lower concentration of CMGs than susceptible ones (Fargette et al., 1990, Colvin et al., 1998); thus, they are poor sources of inoculum from which vectors can acquire and transmit to healthy plants (Thresh et al., 1998a). Virus-resistant varieties sustain little damage or yield loss due to CMD even under conditions of very high inoculum pressure (Thresh et al., 1998b). Moderately resistant and moderately susceptible varieties are tolerant; thus, they show clear disease symptoms, but tend to recover at later stages of crop growth to give economic yields.

Emergence of DNA technologies has facilitated development of novel forms of transgenic resistance to CMG's. The *AC1* gene from ACMV has been integrated into cassava plants to confer resistance to three distinct CMG's, namely ACMV, EACMV-UG and *Sri Lankan cassava mosaic virus*. Development of CMD symptoms in plants carrying *AC1* is suppressed and accumulation of viral DNA is reduced by more than 90% compared to controls (Chellapan et al., 2004). The *AC1* transgene has generated highly resistant plants from previously susceptible cultivars. Other susceptible varieties such as Adhiambolera and Serere that are preferred by farmers could possibly be transformed to build resistance to CMD.

2.3.5. Phytosanitation

This practice involves various measures aimed at improving the health-status of cassava planting materials, thereby enhancing growth and reducing sources of inoculum from which further spread by the whitefly vector could occur (Thresh, 1987). Severe epidemics reported in Uganda until 1944 were controlled using CMD-resistant varieties and phytosanitary measures enforced by the local government (Jameson, 1964). There are five approaches to phytosanitation. (i) Crop hygiene, encompassing removal of all diseased cassava debris, plants, and self-sown previous-crop volunteer-sprouts from within and immediately around areas to be used for new

plantings. (ii) Use of disease-free planting materials for all new plantings, which then establish more readily, grow faster, and yield substantially more than plants grown from infected cuttings, even if infected later by whiteflies (Fargette et al., 1990). (iii) Roguing to remove diseased plants from within crop stands, especially during the early months of growth (Guthrie, 1987). Roguing eliminates initial sources of infection from which further spread can occur. (iv) Removal of weeds or wild plants known to be alternative hosts from within and around crops. (v) Quarantine measures to avoid introducing viruses and their vectors to areas free of them (Thresh, 2003).

Use of virus-free materials for new plantings is beneficial, because such materials establish faster and produce more than infected materials. Virus-free materials eliminate the initial source of virus within crops during the early and most vulnerable stages, thus delaying subsequent spread. Owor (2002) observed that it is possible to maintain a CMD-susceptible cultivar free of CMG infection by growing virus-free plants in a low-spread area. Roguing is widely applied to contain diseases in diverse crops worldwide. It has been adopted in Australia against *Banana bunchy top virus* (Thresh et al., 1998c). Fargette et al. (1990), showed that the rate of spread of CMD is greater in un-rogued than in rogued plots, although the difference was not significant. Thus choice of clean planting material and roguing diseased material might provide effective control in low CMD spread areas. During multiplication of disease-free stock plants for farmers, the health status of the material to be released is very important; thus, losses due to roguing are inevitable and accepted. Roguing is likely to be most effective when practiced by groups of farmers or whole localities.

Official inspection and certification procedures are used to designate and maintain the health status of vegetative propagules being distributed in European and other developed countries. However in Africa, South Africa notwithstanding, little attempt has been made to follow these procedures, except when mandated to meet quarantine requirements so as to facilitate movement of germplasm to other regions (Thresh, 2003).

It is possible to produce virus-free stocks from susceptible local cassava germplasm through tissue culture. Studies have shown that tissue-cultured plants in the field do not express any abnormalities in growth, form or tuber quality (Chisimba and Lingumbwanga, 1996). However, when cuttings from tissue-cultured material, indexed to be CMD-free, and those from farmers' fields were compared, there was no major difference in susceptibility. Thus, use of tissue-

culture-cleaned material in areas of high disease pressure is not very successful, because there is no significant yield advantage (Akano et al., 1996).

2.4. Survey and Cassava Mosaic Disease Management

Surveys are key components of approaches employed to manage CMD; they are important indicative tools, but not means of control. Surveys reveal the incidence and severity of CMD, whitefly-vector populations, and distribution of different CMGs. Survey areas are selected to meet study objectives; administrative boundaries or agro-ecological zones can be used to define sampling domains. If the objective is to relate incidence to yield, whole plant assessments are made, and if it is to relate severity to yield then only the diseased portion is considered. Surveys lead to a better understanding of the etiology and epidemiology of CMD, as well as the biology and bionomics of *B. tabaci* (Sseruwagi et al., 2004a).

2.5. Overview of CMD Management in Kenya for the period 1970-2000

A plant virology research project in the 1970's and 1980's provided the first definitive proof for the etiology of CMD (Bock and Woods, 1983). Evidence from epidemiology trials of this project showed that CMD infection pressure is low in western Kenya (Bock, 1994). However, evidence of significant deterioration in the CMD situation in western Kenya in the mid 1990's was adduced when an overall incidence of 20% and 84% was recorded in 1993 and 1998, respectively. This deterioration led to an urgent need for management options to be developed (Gibson, 1996; Legg et al., 1999a; Legg et al., 1999b).

A project was set up by the International Institute of Tropical Agriculture (IITA) and its partners in the region to mitigate the CMD pandemic in East and Central Africa. The programme has been financed by the United States' Office for Foreign Disaster Assistance (OFDA) since October 1998 to date. In western Kenya, the Kenya Agricultural Research Institute (KARI) Centre at Kakamega coordinates the programme in collaboration with the Ministry of Agriculture. The Gatsby Charitable Trust and the Rockefeller Foundation have been other important development patners contributing to the CMD mitigation work in Kenya. The project has five main objectives, namely: monitoring and diagnostic surveys; germplasm diversification and exchange; rapid multiplication; training; and technology transfer. It undertakes capacity

building as well as project management and monitoring to strengthen networks at national and regional levels that would in turn enhance implementation of project activities (Legg, 2000).

Diagnostic surveys have been carried out since 1998 to track the spread of CMD. Germplasm received from Serere Animal and Agricultural Research Centre in Uganda opened a quarantine facility at KARI-Alupe. The clones were originally tissue-cultured material from IITA Nigeria. To date, 1408 clones have been received (Obiero KARI- Kakamega, personal communication). These clones undergo rigorous evaluations through preliminary yield trials (PYT), advanced yield trials (AYT), on-farm trials and national performance trials (NPT), before they are released to farmers. During PYT clones that are high yielding and tolerant to CMD, CBB and CGM are selected. Clones that yield highly, tolerate CMD, CBB and CGM, contain low to medium cyanide levels, high starch and dry matter content are selected at AYT level. These selections are then taken to on-farm trials for participatory evaluation and acceptability tests in different agro-ecological zones. Clones selected at this stage are taken to NPT where the Kenya Plant Health Inspectorate Service (KEPHIS) is given characteristics of the different varieties. Approved varieties are then released for multiplication and dissemination to farmers (Obiero, 2000). Among the 15 clones released so far, Migyera and SS4 are the most common; MM96/4466 and MM96/7151 have the lowest cyanide content, whereas MH95/0183 and MM96/9308 are the highest yielding, averaging 51 t/ha and 42 t/ha, respectively, at farm level (Obiero et al., 2003).

The selected clones are rapidly multiplied through a three-tier system, consisting of primary, secondary and tertiary levels. Primary level is usually one on station, and has sites at KARI-Kakamega, KARI-Alupe, KARI-Kibos, KARI-Yala swamp, ICIPE-Mbita point, and the Bungoma, Busia, Siaya and Bukura Farmers' Training Centres. Secondary level multiplication sites are in farmers' fields, measuring 2.5 to 5 acres in Western and Nyanza provinces. The tertiary level multiplication sites are also on-farm and can be of any size. They are run and funded by the farmers themselves. This level was adopted to give more farmers in western Kenya access to CMD-free planting material. The area under improved cassava in western Kenya is now 14,000 ha, representing a recovery of about 50% (Obiero et al., 2003). Some of these clones have been used in this research. This is because they have known levels of resistance and we are able to test how effective other CMD management methods are relative to them.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Experiment 1. Survey of Cassava Mosaic Disease and its Whitefly Vector

3.1.1. Survey area and procedure

A major objective of the current survey was to continue monitoring the extent of spread of the CMD pandemic. The surveys were carried out four times to assess cassava mosaic disease (CMD) incidence, CMD severity, and adult whitefly-vector populations. The surveys were conducted in Siaya District in August 2003 and March 2004 and in the wider western Kenya region in September 2002 and October 2003. In Siaya District and western Kenya, site selection was based on divisions and districts as administrative boundaries, respectively. The districts and divisions were not of the same size; similarly, the importance of cassava and hence the frequency of occurrence of cassava in the different areas also varied. Fields sampled were 102 in 2002 and 107 in 2003 in western Kenya; in Siaya District, fields sampled and farmers interviewed were 60 and 35, respectively, in 2003, and 55 and 139, respectively, in 2004. The wide disparity in the number of fields sampled per division in Siaya in 2004 was occasioned by the variation in size of sites and frequency of cassava.

Table 1. Number and proportion of fields sampled in western Kenya in 2002 and 2003

	Number of districts		Number of fields		Fields (%)	
Province	2002	2003	2002	2003	2002	2003
Nyanza	10	9	46	48	45.1	44.9
Rift Valley	3	1	8	4	7.8	3.7
Western	6	7	48	55	47.1	51.4
Total	19	17	102	107	100	100

Fields for sampling were selected at intervals of 4 to 10 km along main roads and alongside paths within villages, depending on the availability of suitable cassava fields, aged between 3 and 6 months after planting (MAP) (Sseruwagi et al., 2004a). More fields were sampled in larger divisions. Thirty plants, selected at regular intervals along two diagonals in the form of an x-shape, were assessed in each field (Otim-Nape, 1993).

Cassava varieties grown, sampling date, age of plants, approximate field size, intercrops, and number of nearby plots with cassava, were recorded. Co-ordinates for each sampled site were recorded using a Global Positioning System (GPS) handset. For western Kenya, co-coordinates were fed into Arcview GIS 3.2 software (Environmental Systems Research Institute Inc., Redlands-California, USA, 1992). Sites were then categorized and distribution maps created for visual representation of CMD incidence and severity, as well as whitefly vectors.

3.1.2. Interview variables

Farmers in Siaya were interviewed on awareness of CMD and management practices such as phytosanition (roguing and choice of CMD-free planting material), as well as identity and sources of resistant varieties. The gender of the person obtaining planting material and of the farmer, and the proportion of each farm planted with cassava were also noted. Reasons for intercropping, adoption of varietal mixtures, and mode of harvest and post-harvest technology were also queried. Interviews were carried out using the questionnaire in Appendix 1.

3.1.3. Variables measured

(a) Disease or symptom severity

Disease severity indicates the proportion of diseased area relative to the total area of a plant tissue (Krantz, 1988). Severity was estimated and expressed as the proportion or percentage of a plant tissue with symptoms of the disease (Table 2).

Table 2. Scale for scoring cassava mosaic disease symptom severity

Scale	Severity
1	Apparently healthy shoots, no symptoms
2	Mild chlorosis, little or no leaf distortion, most leaflets appear normal-green
3	Pronounced mosaic pattern, minor narrowing of 1/3 of most leaflets, moderate chlorosis of shoots
4	Severe mosaic, distortion of 2/3 of most leaflets, general reduction of leaf size, some stunting of shoots
5	Very severe chlorosis, distortion, twisting, malformation and severe reduction of most top leaves into candle-stick shape, severe stunting of plants

(b) Disease incidence

This variable refers to the proportion of plants that are visibly diseased relative to the total number of plants assessed (Krantz, 1988). Cassava mosaic disease incidence was calculated using the formulae: CMD incidence (%) = {number of plants with symptoms/number of plants assessed} x 100.....(Equation 1)

(c) Type of infection

Cassava mosaic disease infection was categorized based on source, which included current season infection by the whiteflies (W), diseased (C) or healthy (H) cuttings. The type of infection was expressed as a percentage of the total sample (diseased plants) collected per field.

(d) Adult whitefly population

The population of adult whiteflies was assessed on each plant sampled. The adult whiteflies on the youngest five expanded apical leaves of the tallest shoot were counted. Each leaf was held gently by the petiole and turned over to count the number of adults on the lower surface. The average number of whiteflies per plant was calculated for each sampled field.

(e) Type of virus in CMD-affected plants in western Kenya

(i) Sample collection

A newly emerged leaf showing CMD symptoms was collected from the uppermost shoot of a plant selected to represent the general disease situation in the field visited. An approximately 1-cm^2 portion of this leaf was cut and placed in a microfuge tube. The tube was labelled and placed in a cool-box to await DNA extraction that was carried out later on the same day.

(ii) DNA extraction

Viral DNA was extracted from the leaf portion using a protocol modified from that of Dellaporta et al. (1983). Leaf samples were cut and ground with kontes pestles in a microfuge tube containing 500 µl of extraction buffer (dellaporta). About 33 µl of 20% lauryl sulphate, which acts as a detergent to remove high molecular mass proteins, was added to each tube. Contents were then mixed thoroughly and incubated in a water bath at 65°C for 10 minutes. About 160 µl of 5-M potassium acetate was added to each tube and mixed thoroughly to precipitate salts. The contents were incubated in an icebox for 10 minutes and centrifuged at

13000 rpm in a microfuge. About 450 µl of the resultant supernatant was removed and put in a new tube to which 450 µl of cold isopropanol was added. The contents were mixed by inverting the tube and spun at 13000 rpm at room temperature to precipitate the DNA. The supernatant was carefully pipetted off, leaving behind the DNA. To remove soluble organic ions, the DNA pellets were washed in 500 µl of 70% ethanol by centrifuging at 13000 rpm for five minutes. The supernatant was again pipetted off, leaving behind the DNA, which was air-dried to evaporate ethanol, and thereafter re-suspended in 300 µl of distilled water to make stock DNA for later use.

(iii) Polymerase chain reaction procedure

This was carried out at the IITA-ESARC virology laboratory at Namulonge in Kampala, Uganda. DNA-A was cut using restriction enzymes to characterize CMG variability. Thermocycler reactions, which are temperature-dependent, were performed to amplify targeted sequences of DNA many times in a chain reaction. In the present study, universal oligonucleotide primers were used to amplify near-full-length fragments of the DNA-A of CMGs from the whole plant extract. Specific primers for ACMV and EACMV's were used to confirm diagnoses of the various CMG's (Zhou et al., 1997; Okao-Okuja et al., 2004).

An equal amount of 5 µl of the diluted DNA template was added to the reaction mixture and layered with a drop of mineral oil to prevent evaporation during thermocycling. Amplification was performed using *Taq* DNA polymerase (Sigma, Poole, UK). Reaction mixture for one sample consisted of 10.6 µl of distilled water, 2.5 µl thermobuffer, 1.5 µl of 25 mM magnesium chloride, 2.5 µl of 5% Tween 20, 0.2 µl *Taq* polymerase (1 Unit), 0.2 µl of 2.5 mM dNTPs and 0.2 µl each of pairs of universal or specific oligonucleotide primers. The samples were then loaded into a thermocycler with the first cycle of 1 minute at 94°C, followed by 35 cycles of 1 min at 94°C, 1 hour and 30 minutes at 55°C, and 2 minutes at 72°C; a final extension was run for 10 minutes at 72°C. Approximately 18 µl of the amplified DNA for each sample was mixed with 1 µl of loading dye and loaded together with a DNA ladder marker onto a 1.2% agarose gel. The gel was prepared by dissolving 1.2 g agarose in 100 ml of Tris acetate EDTA buffer, heating to boiling point and leaving to cool. Approximately 10 mg/ml ethidium bromide solution was added to the gel mix to allow for subsequent DNA staining. The gel was then poured into a gel-moulding tray, pre-fitted with a well-opening comb. After solidifying, the

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comb was withdrawn, the gel lifted from the gel-moulding tray and immersed into an electrophoresis tank. Tris acetate EDTA buffer was poured into the tank to cover the gel.

Following loading of the wells with samples, the tank was connected to a power supply and run at 80 Volts for one hour. The gel was removed from the tank and placed under a UV light trans-illuminator to observe DNA bands, followed by photographing with a Polaroid Gelcam camera (Polaroid, Luton, UK). The sizes of amplified DNA fragments for each sample were estimated through comparison with the bands of the DNA ladder marker.

3.1.4. Data analysis

Averages of interview data were calculated for the different responses and converted to percentages, when appropriate. The interview data were then subjected to descriptive-statistics analysis. Number of plants within each severity score for each major region (district/division) were subjected to chi-square analysis for comparing regions in a given year (season), as well as seasons one and two for a given district/division. The Statistical Analysis System (SAS) software (SAS, Cary-North Carolina, USA, 1999) was used to perform the chi-square analysis. Frequency distribution of total CMD incidence in fields assessed in the different regions during the two seasons was calculated and compared using the Mann-Whitney Wilcoxon test. Relationships between the different parameters recorded in the survey were determined using the Pearson's correlation test of mean values for each region.

To determine the effect of multiple infections, whitefly incidence values were presented as multiple infection units (MIU) as described by Gregory (1948). Calculation of MIU used the formula: $Y = \log_e (1/(1\text{-}C\text{-}W)) - \log_e (1/(1\text{-}C))$, where W represents proportion of plants with whitefly-borne CMD, 1 indicates 100% CMD-infected, and C designates proportion of plants with cutting-borne CMD.....Equation 2.

Recorded geographical coordinates for each sampled site were used to map visual representation of the distribution of CMD severity and incidence, as well as adult whitefly population in western Kenya. Map analysis was done using Arcview software (Environmental Systems Research Institute, Redlands-California, USA, 1992).

Analysis of CMG's DNA data was done based on the fact that digestion of DNA-A with *Eco*RV typically gives diagnostic banding patterns, whereby ACMV yields two bands of approximately 1480 and 1284 base pairs (bp), while EACMV's yields two bands of

approximately 2197 and 585 bp (Legg and Thresh, 2003). Digesting the bands with *Mlu*I provides information on variability within these two major groups. There are two commonly occurring *Mlu*I-digested restriction fragment polymorphs in ACMV; a single uncut DNA-A fragment of 2764 bp characterises the first, whereas two bands of 1552 and 1212 bp characterises the second (R. Briddon, unpublished data). In contrast, *Mlu*I cuts EACMV's into three to five fragments with the largest approximating 1212 bp (Legg and Thresh, 2003).

3.2. Experiment 2. Measurement of CMD Inoculum Pressure in Siaya District

3.2.1 Experimental site, design and layout

Trial sites were located in 4 of the 7 divisions of Siaya District, namely Ukwala, Ugunja, Karemo, and Yala that were selected based on accessibility, particularly of Ugunja division. Apparently CMD-free stems of Bukalasa 11/Serere (moderately susceptible) and TMS 30572/Migyera (moderately resistant) were chosen for planting.

The experiment was set up as a 2 x 4 factorial experiment in a completely randomised design with the first factor being variety and the second factor being location, represented by the divisions. Two adjacent plots measuring 4 m by 9 m were laid down, with no gaps between the plots; each plot was planted with 50 cassava stems at a spacing of 1 m x 1 m. Trials were planted during the short rains in October 2002 and September 2003, following local agronomic practices. Plants sprouting in the test plots while exhibiting symptoms of CMD and plants that did not sprout were replaced with symptomless plants from adjoining nursery plots.

UGUNJA DIVISION	
TMS 30572 (Migyera)	Bukalasa 11 (Serere)

UKWALA DIVISION	
Bukalasa 11 (Serere)	TMS 30572 (Migyera)

YALA DIVISION	
Bukalasa 11 (Serere)	TMS 30572 (Migyera)

KAREMO DIVISION	
TMS 30572 (Migyera)	Bukalasa 11 (Serere)

Figure 1. Experimental layout for the study on measurement of cassava mosaic disease inoculum-pressure in Siaya District.

3.2.2 Variables measured

(a) Incidence of CMD was determined indirectly from severity data, as described in Equation 1.

(b) Disease or symptom severity was determined on whole plants for all plants, using the 1 to 5 scale described in Table 2. Data were recorded monthly from 1 to 8 MAP.

(c) Adult whiteflies were counted monthly from 1 to 8 MAP, on the five top-most expanded apical leaves of the tallest shoot for each plant.

(d) Inoculum pressure, based on the abundance and proximity of CMD-affected cassava in the immediate surroundings of the trial sites, was assessed using a simple mapping exercise at 2 MAP. For each cassava planting within a 250-m radius of each trial site, the total number of plants (N), proportion infected with CMD (C), and distance from the trial site (D) were estimated. Simple maps were drawn indicating the position and approximate dimensions in metres of surrounding cassava fields, relative to the trial site. The estimates were used to calculate a single CMD inoculum availability index (S) for each trial site, using the formulae:

$S = \Sigma_{i=1=n} N_iC_i/D_i$ or $N_1C_1/D_1 + N_2C_2/D_2...N_nC_n/D_n$ (Legg et al., 1997).....(Equation 3).

(e) Virus diagnosis to identify the different virus strains was done by collecting samples of newly emerged leaves from the uppermost shoot of an infected plant and subjecting to PCR diagnostics, as described for the survey experiment. Samples were collected from each site at 6 MAP of the 2002 season. The Universal Primers UNIF and UNIR (Invitrogen, Life Sciences, St. Louis, MO, USA) were used to amplify near full-length DNA-A fragments of CMG's from the DNA extracts for each sample. DNA-A was then cut using the restriction enzymes *Eco*RV and *Mlu*I to characterize CMG variability.

3.2.3. Data analysis

General linear model analysis of variance was carried out to determine the effects of site (divisions) and variety on CMD severity and incidence, as well as the whitefly-vector for each year (season), using the Genstat software (Lawes Agricultural Trust, Rothamsted, UK, 2003). Symptom severity scores of Migyera and Bukalasa 11 in the different divisions were compared, through chi-square tests, using SAS software (SAS, Cary-North Carolina, USA, 1999).

Regression analysis was used to determine relationships between CMD inoculum pressure indices and arcsine-transformed adult whitefly population, or CMD incidence

percentages, for each site. Regression analysis was done using the Genstat software (Lawes Agricultural Trust, Rothamsted, UK, 2003).

3.3. Experiment 3. Effects of CMD and Variety on Growth and Yield of Cassava

3.3.1 Experimental site, design and layout

The experimental design consisted of subplots in randomised complete blocks, replicated three times. The CMD status was assigned to main plots and varieties to subplots. Two diseased conditions, healthy and diseased, were tested. Varieties were selected to represent different susceptibility levels; thus, Bukalasa11/Serere (moderately susceptible), TMS 30572/Migyera (moderately resistant), and Karemo/Oyombo (susceptible). A replication had 6 plots, each measuring 6 m by 5 m, and 42 plants at plant-to-plant spacing of 1 m. The net plot excluded the outer guard row of MM96/4466 — a CMD-resistant variety.

This experiment was planted in October 2003 at one site in Ugunja division, isolated from other cassava farms. The initially CMD-infected cuttings were obtained from diseased stock plants, whereas initially CMD-free cuttings were obtained from apparently CMD-free stock plants. Mature stems of all varieties were obtained from the first planting of Experiment 2 at Ugunja, except for CMD-infected Migyera that was obtained from a farmer's field in Ukwala.

Spreading of CMD was prevented through management of whiteflies, using two pesticides: imidacloprid, immediately cassava cuttings sprouted and at 4 MAP; and dimethoate (a contact insecticide), weekly for the first three months.

Replication I	CMD-free	Bukalasa 11 (Serere)	Karemo (Oyombo)	TMS 30572 (Migyera)
	CMD-infected	TMS 30572 (Migyera)	Bukalasa 11 (Serere)	Karemo (Oyombo)
Replication II	CMD-free	Karemo (Oyombo)	TMS 30572 (Migyera)	Bukalasa 11 (Serere)
	CMD-infected	TMS 30572 (Migyera)	Karemo (Oyombo)	Bukalasa 11 (Serere)
Replication III	CMD-infected	Bukalasa 11 (Serere)	TMS 30572 (Migyera)	Karemo (Oyombo)
	CMD-free	Karemo (Oyombo)	Bukalasa 11 (Serere)	TMS 30572 (Migyera)

Figure 2. Experimental layout for the study on estimation of yield loss due to CMD in selected cassava varieties grown in Siaya District.

3.3.2 Variables measured

(a) Disease or symptom severity was determined on whole plants for all plants, using the 1 to 5 scale described in Table 2. Data were recorded at 1, 3, 7 and 10 MAP.

(b) Growth variables (plant-height, number and circumference of stems) were assessed for five plants randomly selected within each net plot at 3, 7 and 10 MAP. Plant-height was measured from the ground level to the highest shoot tip. The total number of stems for the five plants was counted and their circumference measured. The number of stems bearing symptoms of CMD was also recorded.

(3) Yield data collected at harvest included plant biomass and tuberous roots (number and fresh weight) for each plant. Biomass yield was recorded for each plant by harvesting and weighing

fresh weight of all the above ground parts on each plant. Tuberous roots were separated on the basis of size into marketable and non-marketable roots. Harvest index (HI) was computed using the formula: HI = total fresh weight of tuberous roots per plant/above ground biomass per plant + total fresh weight of tuberous roots per plant Cock et al. (1979).....(Equation 4).

3.3.3. Data analysis

Frequency of severity score categories was recorded every month for each plant and variety. Frequencies were subjected to chi-square analysis, using the SAS software (Cary-North Carolina, USA, 1999). Data on symptom severity, stem circumference, plant height, above ground biomass and tuberous root yield were subjected to analysis of variance, using the Genstat software (Lawes Agricultural Trust, Rothamsted, UK, 2003). Relationships between symptom severity indices and plant growth variables, or yield performance, were determined through regression analysis, using the SAS software (SAS, Cary-North Carolina, USA, 1999).

3.4 Experiment 4. Effects of Cultural Methods and Resistance in the Control of CMD

3.4.1 Experimental site, design and layout

This experiment was set up as a 4 x 4 factorial arrangement in completely randomized design with four replications for each site. A replication had 16 plots, each measuring 4 m x 4 m, and having 25 plants, spaced at 1 m x 1 m apart in a 5 x 5 array. All plots were planted with CMD-free material in the first year. Sites were located in two divisions (Karemo and Ugunja) of Siaya District that were chosen because previous surveys indicated contrasting patterns of CMD spread; Karemo showed low spread, while Ugunja revealed high spread (Obiero et al., 2001).

The four varieties planted were selected on the basis of their relative susceptibility to CMD as: MM96/4466 (resistant = V1), TMS 30572/Migyera (moderately resistant = V2), Karemo/Oyombo (susceptible = V3), and Bukalasa 11/Serere (moderately susceptible = V4). Apparently CMD-free mature stems were obtained as follows: MM96/4466 from KARI-Alupe; TMS 30572 from KARI-Kakamega; Bukalasa 11 from a farmer's field in Rodi-Kopany, Homabay district; and Karemo from a farmer's field in Karemo, Siaya District. Nursery plants for each of these varieties were established at each site and subsequently used to replace plants that sprouted while showing cassava mosaic virus symptoms, and for gapping plants that failed to sprout. The four management practices were: roguing once at 12 weeks after planting (WAP)

(T1), choice of CMD-free stems for planting (T2), combination of roguing and choice of planting material (T3), and control (T4). The 16 treatments were assigned randomly to the 16 plots.

The trials were first planted in October 2002. Any plants sprouting while showing disease symptoms were removed at six WAP in all plots. In the second year, cuttings obtained from the first planting were used to replant (repeat) the experiment as follows: five stems were selected in control plots using random numbers; in the choice of planting material plots, five CMD-free stems were selected at random; where CMD-free plants were not present, the most vigorous of the diseased stems was selected. Plants expressing CMD symptoms at sprouting were recorded and only removed in the roguing treatment, as described for the initial planting of this experiment. The repeat planting was done in October 2003. The trials were planted in exactly the same sites during the repeat season, as is the common practice of farmers in the study region.

Replication I

1	2	15	14	11	10	6	12
9	5	4	13	7	3	8	16

Replication II

2	12	9	3	8	11	5	4
10	1	13	6	15	7	16	14

Replication III

9	6	3	14	2	16	7	12
1	15	11	5	13	10	8	4

Replication IV

16	3	7	10	5	14	9	12
8	15	11	4	2	13	6	1

Figure 3. Experimental layout for the study on effects of cultural methods and resistance in the control of cassava mosaic disease. 1=V1T1, 2=V1T2, 3=V1T3, 4=V1T4, 5=V2T1, 6=V2T2, 7=V2T3, 8=V2T4, 9=V3T1, 10=V3T2, 11=V3T3, 12=V3T4, 13=V4T1, 14=V4T2, 15=V4T3, and 16=V4T4, as described previously.

3.4.2. Variables measured

(a) Disease or symptom severity was determined on whole plants for all plants, using the 1 to 5 scale described in Table 2. Data were recorded monthly from 1 to 8 MAP.

(b) Incidence of CMD was determined indirectly from severity data, as described in Equation 1.

(c) Adult whiteflies were counted on the five top-most expanded apical leaves of the tallest shoot on five plants along one diagonal in each plot. The youngest leaves are epidemiologically important because they harbour most of the adult whiteflies and are the most susceptible to infection (Fondong et al., 1997). Whiteflies were counted monthly from 1 to 8 MAP.

(d) Yield variables: in the repeat planting, biomass was recorded by harvesting and weighing (fresh weight) of all the above ground parts for each plant. Tuberous root yield data were recorded at 8 MAP and included the number and fresh weight of tuberous roots for each plant. Tuberous roots were separated on the basis of size into marketable (big) and non-marketable (small). Growers usually retain non-marketable tuberous roots for drying to make chips, or flour.

3.4.3. Data analysis

Data for CMD incidence and severity were not subjected to analysis of variance because only some of the varieties became affected. Whole plant CMD severity data were subjected to chi-square tests to determine differences in severity score distribution. Chi-square analysis was done using the SAS software (SAS, Cary-North Carolina, USA, 1999).

Adult whitefly population, plant biomass, and tuberous root yield data were subjected to 4 x 4 factorial analysis of variance to determine effects of varieties and management practices, using the Genstat software (Lawes Agricultural Trust, Rothamsted, UK, 2003). Tuberous root yield in Karemo variety for the management practices versus the control were subjected to paired t-test comparisons. Similar analysis was done for the Karemo variety versus the two resistant varieties in the choice of planting material and control plots, using the Genstat software (Lawes Agricultural Trust, Rothamsted, UK, 2003).

CHAPTER FOUR

RESULTS

4.1. Experiment 1: Survey of Cassava Mosaic Disease and its Whitefly Vector

4.1.1. History of cassava mosaic disease

Most farmers interviewed were aware that there was a problem with their cassava crops, but they did not know that the problem was due to cassava mosaic disease (CMD). When asked leading questions, most farmers positively identified CMD and gave the years when they first noticed its devastating effects. The greatest proportion of farmers noticed it between 1997 and 2001 (Figure 4).

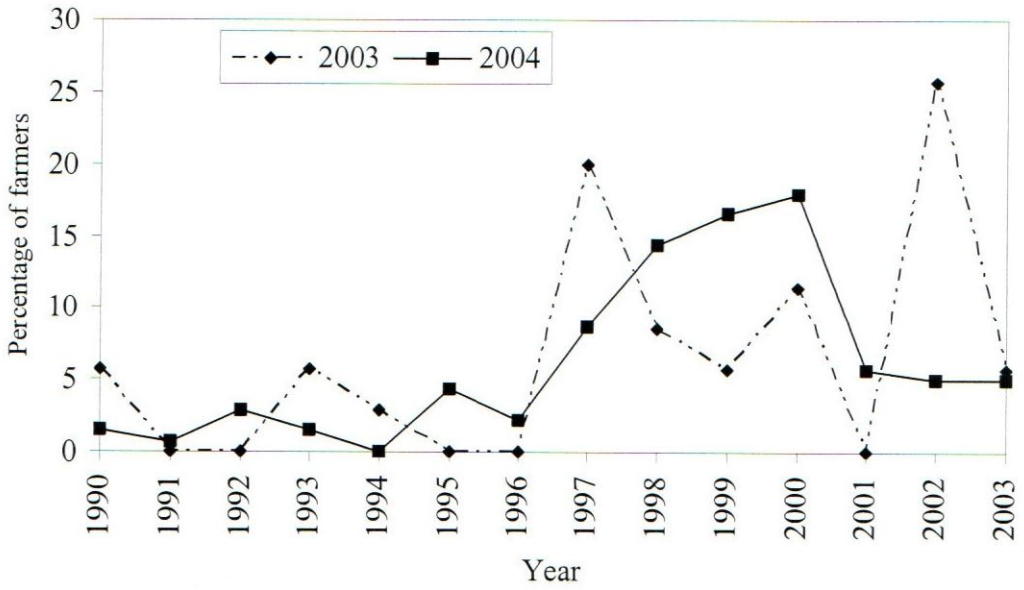


Figure 4. Year when CMD was first noticed as reported by farmers in Siaya in 2003 and 2004

4.1.2. Cassava mosaic disease management measures

Most farmers did little to control CMD when they first noticed it; instead they abandoned cassava production when CMD damaging effects intensified. Some of the farmers tried to improve crop husbandry practices, although none of them tried chemical control (Table 3).

Table 3. Methods tried by farmers to control cassava mosaic disease

Method	Number of farmers	Percentage of total
Weeding	1	0.7
Spraying ash	2	1.1
Roguing	3	1.7
Selection	4	2.3
Fertilizer	4	2.3
Rotation	6	3.4
Different variety	8	4.5
Nothing	150	84.4

(a) Growing of alternate crops

Of the farmers interviewed, an average of 67%, corresponding to 63% and 68% of respondents in 2003 and 2004, respectively, stopped growing cassava as a result of CMD. Instead, 62% in 2003 and 43% in 2004 switched to, or increased growing of sweet potato, maize and sorghum; other alternative crops taken up included millet, beans and groundnuts (Figure 5).

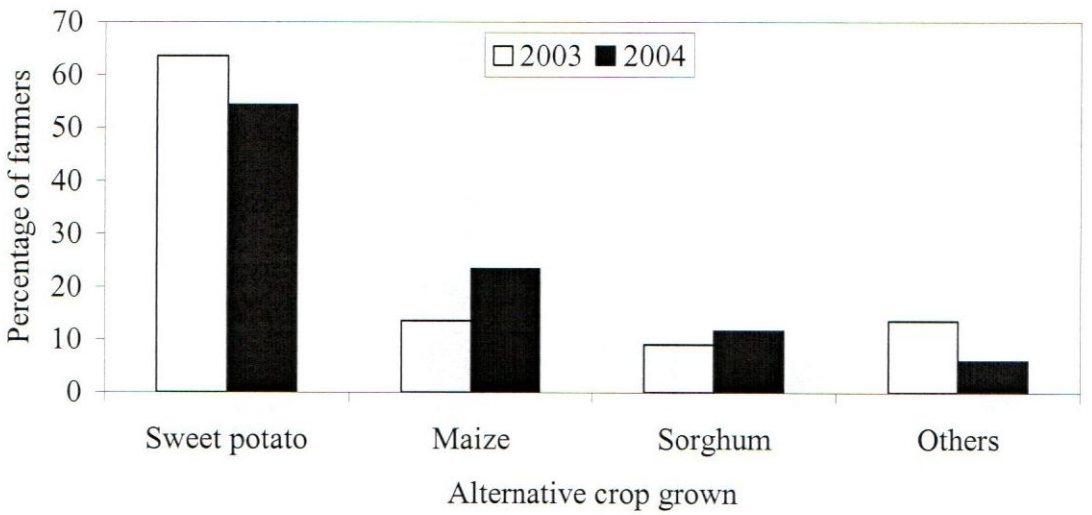


Figure 5. Alternative crops grown instead of cassava

(b) Phytosanitation through choice of planting material

About 71% of the farmers interviewed were not aware of the beneficial effects of choice of clean planting material and hence did not practise it. Those who opted to choose (29%) did it based on the absence of disease, large stem size, high yields and high number of nodes.

(c) Phytosanitation through roguing

Only 15% of the farmers interviewed practised roguing in their cassava fields. Of these farmers, about 37% practised roguing as they weeded, 51% practised roguing between 1 and 4 months after planting (MAP), 4% practised roguing at anytime, and 4% practised roguing at harvest time.

4.1.3. Cassava production

Most of the farmers interviewed (98%) had some cassava in their farms; however in most cases, less than a quarter of the land in these farms was planted with cassava (Figure 6). It is noteworthy that small areas of cassava provided high yields and land-use-efficiency.

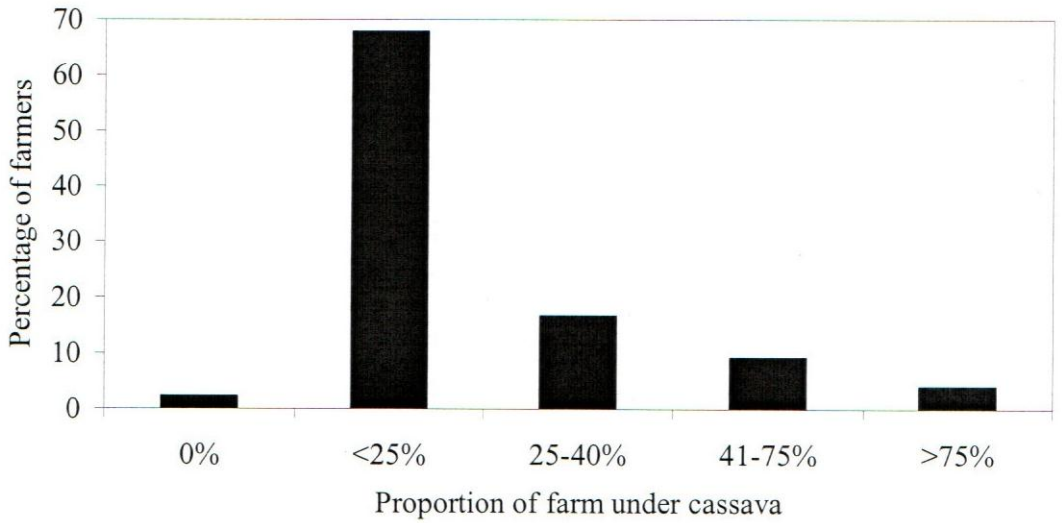


Figure 6. Proportion of farms planted with cassava

4.1.4. Agronomic practices

(a) Variety

Both local landraces and improved varieties were encountered during the surveys in Siaya District. Local CMD-susceptible landraces in varietal mixtures were most frequent, while the most common improved variety was Migyera, occurring in seven fields in 2003, and one fields in 2004 (Tables 4 and 5).

Table 4. Common varieties planted by farmers interviewed in Siaya District in 2003 and 2004

Division	Variety
Boro	Adhiambolera, Oyombo, Migyera, Nyamasumbi, Kamis
Karemo	Oyombo, Nyamasumbi, Nyanek, Adhiambolera
Ugunja	Adhiambolera, Nyanthaga, Chongedongo, Rateng, Nyadai, Migyera
Ukwala	Nyadai, Migyera, Adhiambolera, Liech gumbo, Matuja, Nyauganda,
Uranga	Nambamnana, Ebwanatereka, Kamis, Nyauganda, Jumamit, Oyombo,
Wagai	Adhiambolera, Kamis, Oyombo, Rateng
Yala	Adhiambolera, Nyanthaga, Migyera, Nylon, Kamis

Table 5. Varieties occurring in 2 or more fields, incidence of CMD (%), and average number of adult *B. tabaci* on top five leaves per plant in Siaya District in 2003 and 2004

2003				2004			
Variety	Fields	CMD	Whiteflies	Variety	Fields	CMD	Whiteflies
Adhiambolera	21	82.3	1.3	Adhiambolera	22	73.0	16.5
Kamis	2	98.3	0.4	Bukalasa 8	2	68.3	8.1
Liech gumbo	2	58.3	1.3	Jumamit	3	65.6	68.3
Matuja	2	78.3	0.4	Kamis	3	92.2	35.1
Migyera	7	28.1	0.9	Nambamnana	2	98.3	77.0
Nyamasumbi	6	87.8	0.3	Nyadai	2	61.7	5.2
Oyombo	4	81.7	0.4	Nyakendu	2	100.0	17.8
Ebwanatereka	2	66.7	1.4	Nyamasumbi	2	100.0	16.0
				Nyauganda	2	96.7	32.3
				Rateng	3	70.0	10.8

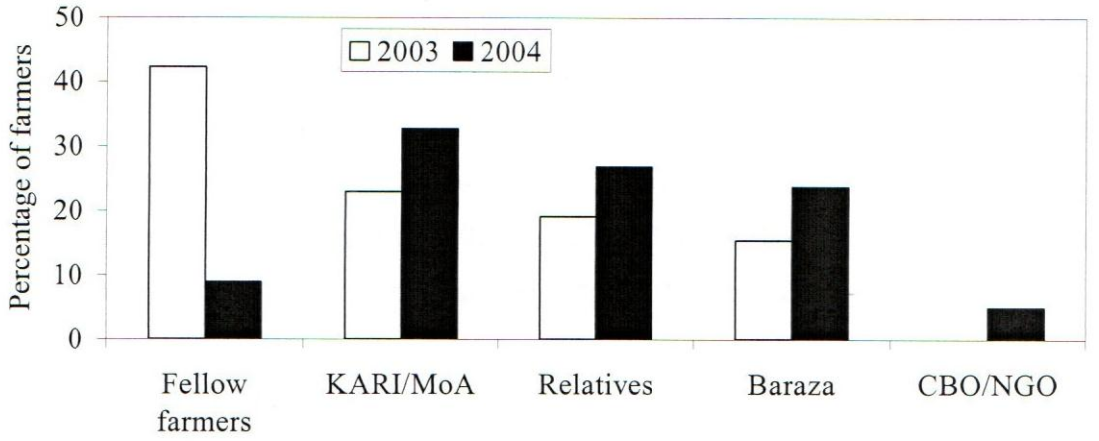


Figure 7. Source of information about resistant varieties. KARI = Kenya Agriculture Research Institute; MoA = Ministry of Agriculture; CBO = community based organization; NGO = non-governmental organization.

In parts of Ukwala, Ugunja and Yala that border Western province, improved varieties were more common. Ukwala and Uranga areas occupied by the Samia people, who interact a lot with Ugandans, had several Ugandan local varieties, commonly known as Nyauganda, including Ebwanatereka and Nambamnana. In Wagai division, there was no improved variety and the area generally had little cassava. Adhiambolera was the most common variety occurring in 35% and 40% of fields sampled in 2003 and 2004, respectively (Tables 4 and 5).

Farmers' preference of variety varied with division (Table 4). Most farmers were not aware of the tremendous work done by KARI and other collaborators in multiplication of CMD-resistant varieties (Figure 7). Of the farmers interviewed in 2003, only 25.7% were aware, although none had planted CMD-resistant varieties. About 48.2% of those interviewed in 2004 were aware and 40.3% of them had planted them (Figure 7). It is noteworthy that most farmers who had information about CMD-resistant varieties got it from KARI, the MoA, and local chiefs' meetings (barazas) that received the information from the first two sources (Figure 7). Farmers generally claimed to have no access to resistant varieties, and stated that although chiefs and agricultural officers had mentioned them, they had not provided the material. Other local leaders and extension workers sell the material, which farmers opt not to buy, but continue planting local CMD-susceptible landraces. A few farmers were afraid of planting resistant varieties, as they had heard that such varieties kill through their high toxic cyanogens.

(b) Intercropping

Of the farmers interviewed, 42% intercropped their cassava; 56% of those who intercropped did so for food security, 32% because of land scarcity and 12% for other reasons. The most common intercrops were maize, cowpea, sweet potato, sorghum and finger millet. Many people intercropped during the long rains. The crops surveyed in 2003 were planted during the long rains and those surveyed in 2004 were planted during both the long and short rains. Of the fields surveyed, 66.7% and 43.6% had intercrops in 2003 and 2004, respectively.

(c) Source of planting material

Farmers in Siaya District mainly share planting materials amongst themselves. The most common sources were relatives, fellow farmers, or recycling of previous season's planting material (Figure 8). Farmers, especially in Uranga division, sourced their material from relatives based in Uganda. Very few farmers obtained planting materials directly from KARI or the Ministry of Agriculture (MoA) extension centres (Figure 8). The current survey showed that women were most heavily involved in sourcing planting materials, either on their own or with assistance from men (Figure 9).

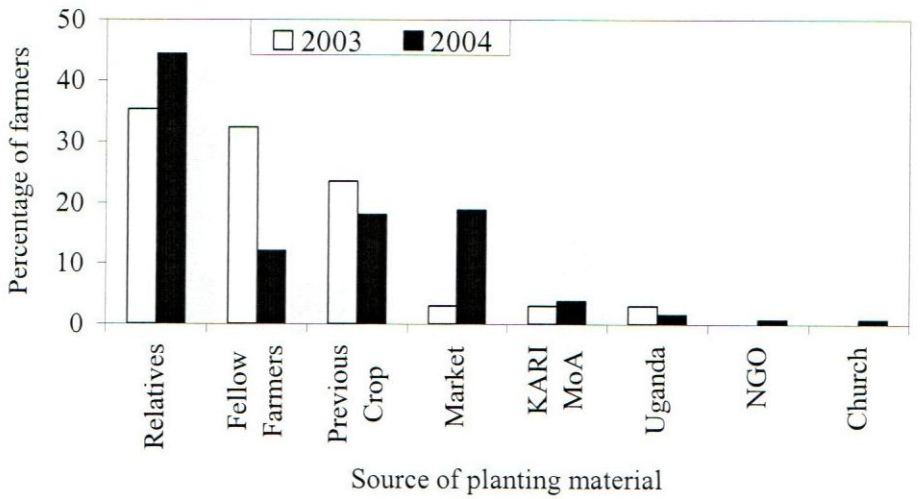


Figure 8. Farmers' sources of planting material in Siaya District during 2003 and 2004

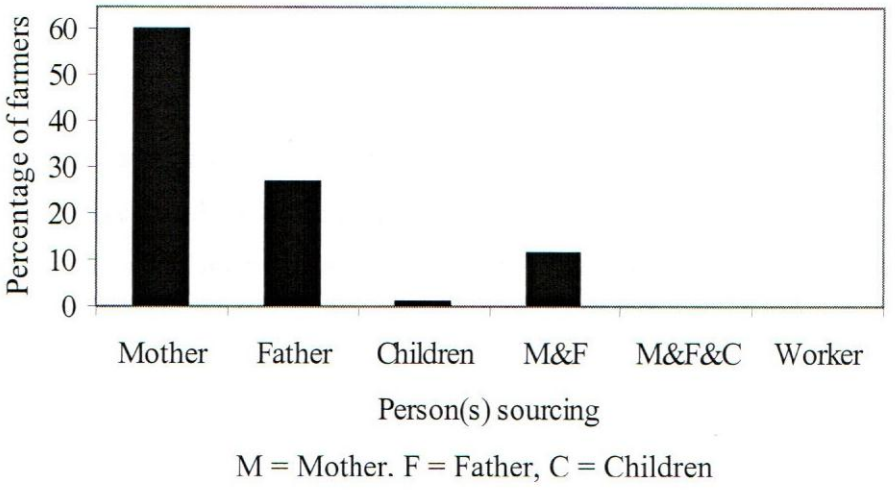


Figure 9. Percentage of different family members sourcing the planting materials

(d) Labour

Women were more involved in working on the farm, where they performed weeding and maintenance of the cassava crop (Figure 10). Most people interviewed said they preferred women working on root crops because women workers caused less damage to tubers. Even where other family members did maintenance, women performed 100% of the harvesting tasks.

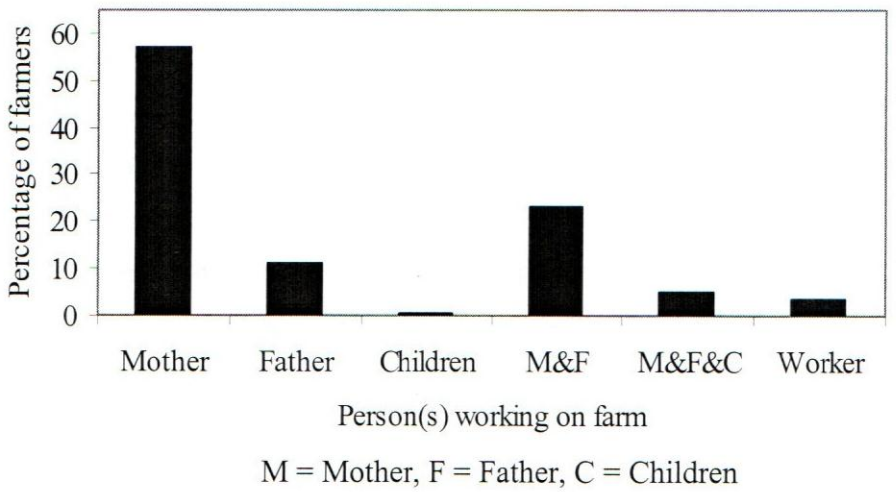


Figure 10. Percentage of different family members working on cassava farms

(e) Harvesting

Harvesting of cassava is done either piecemeal (on several occasions over a period of time), or once-over. Piecemeal means that farmers harvest only a small proportion of the crop to boil and eat as '*ateda*', or to process into flour ('*mogo*'). Once-over farmers harvest the whole crop on one occasion to process into flour. Varieties are classified as either '*ateda*' or '*mogo*' in the local language, depending on the use, and most farmers usually harvest the '*ateda*' variety piecemeal and the '*mogo*' variety once-over.

The proportion of farmers practising piecemeal harvesting was 60% and 84%, and once-over was 20% and 12.9% in 2003 and 2004, respectively. A few farmers practiced both types of harvesting, and these were 20% and 2.8% of those interviewed in 2003 and 2004, respectively.

4.1.5. Disease (symptom) severity

Cassava mosaic disease severity of affected plants ranged from 2.0 to 3.0, and most affected fields revealed mild to moderate symptoms. Severity was highest in Nyanza (2.8 to 2.9) and lowest in Rift Valley (2.5) during both of the western Kenya surveys (Figures 11a and 11b). There were significant differences between districts surveyed in 2002 and 2003 (Table 6a). Of the total 14 districts that were surveyed, Busia varied less significantly ($P<0.05$), compared to the rest ($P<0.01$), when severity scores of the two years were analysed. In Nyando and Kuria, variations were not significant between the two years. Rachuonyo and Lugari revealed a decrease in severity, while all the rest showed an increase. The highest severity scores of 3.6 and 3.5 were recorded in Gucha during 2002 and in Busia during 2003, respectively. In 2002, West Pokot had only clean plants with a severity score of 1.0; the lowest severity scores were 2.1 and 2.3 in Migori during 2002 and in Vihiga during 2003, respectively.

In Siaya District, the average symptom severity score was 2.6 during 2003 and 2.5 during 2004. There were very significant differences in severity scores between divisions in each year and also in each division during the two years. Highest score of 2.9 was in Yala during 2003, while the lowest score was 2.5 in Wagai during 2004. Except for Karemo and Ukwala that maintained their severities, the rest of the districts experienced increased severity (Table 6b).

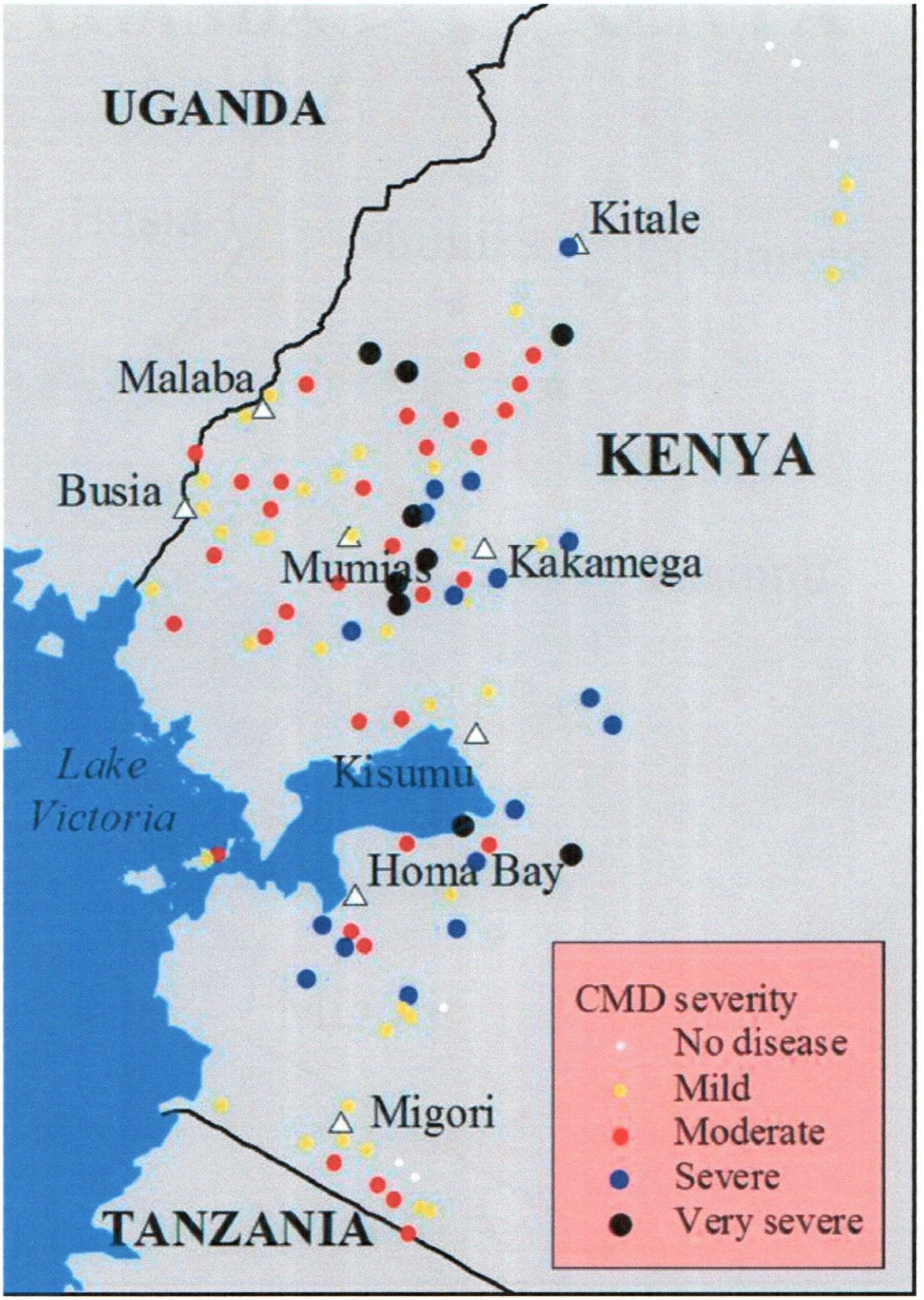


Figure 11a. Severity of cassava mosaic disease in western Kenya during 2002

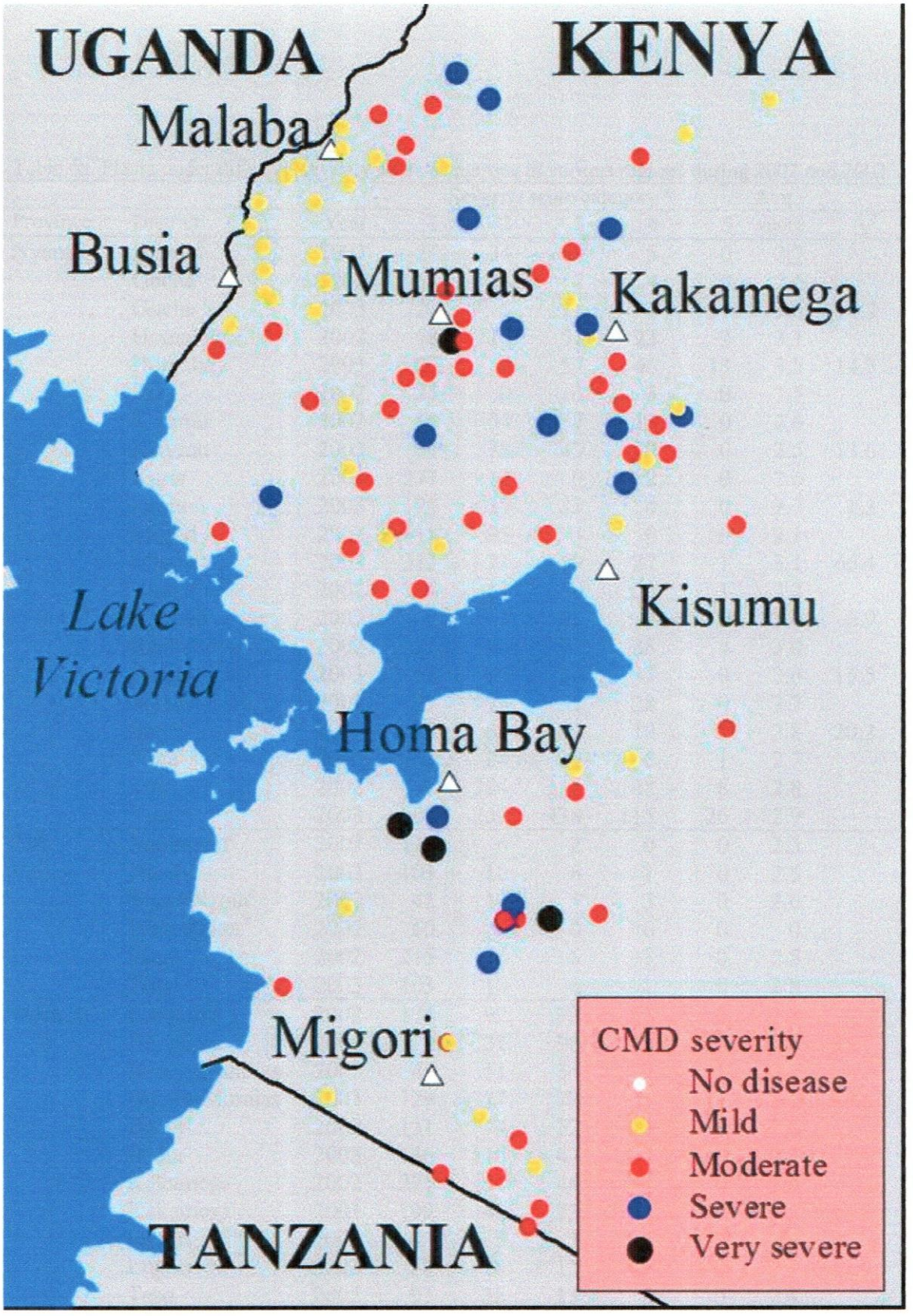


Figure 11b. Severity of cassava mosaic disease in western Kenya during 2003

Table 6a. Plants under different severity score categories in various regions during 2002 and 2003

			Severity score category [y]					Avg.		
Province	District	Year	1	2	3	4	5	score	χ^2	Sign.
Nyanza	Bondo[z]	2003	27	34	54	5	0	2.7		
	Gucha	2002	63	16	7	4	0	2.6		
	Gucha	2003	23	8	11	7	11	3.6	14.2	**
	Homabay	2002	58	16	51	23	2	3.1		
	Homabay	2003	26	8	57	46	13	3.5	14.3	**
	Kisii[z]	2002	24	0	3	3	0	3.5		
	Kisumu	2002	16	54	37	13	0	2.6		
	Kisumu	2003	69	38	43	0	0	2.5	13.6	***
	Kuria	2002	277	12	9	2	0	2.6		
	Kuria	2003	178	25	33	4	0	2.7	1.3	NS
	Migori	2002	111	35	4	0	0	2.1		
	Migori	2003	212	21	69	27	1	3.1	66.4	***
	Nyando	2002	6	12	69	32	1	3.2		
	Nyando	2003	0	3	25	2	0	3.0	6.9	NS
	Rachuonyo	2002	21	40	77	38	4	3.0		
	Rachuonyo	2003	67	26	24	3	0	2.6	15.5	NS
	Siaya	2002	25	75	52	28	0	2.7		
	Siaya	2003	48	63	109	19	1	2.8	20.2	***
	Suba[z]	2002	1	24	29	5	1	2.7		
	Total	2002	602	284	338	148	8	2.8		
	Total	2003	609	252	438	115	26	2.9		
Rift Valley	Marakwet[z]	2002	112	6	2	0	0	2.3		
	Nandi[z]	2003	103	10	6	1	0	2.5		
	Trans Nzoia[z]	2002	42	10	5	3	0	2.6		
	West Pokot[z]	2002	60	0	0	0	0	0		
	Total	2002	215	16	6	3	0	2.5		
	Total	2003	103	10	6	1	0	2.5		
Western	Bungoma	2002	174	92	73	51	0	2.8		
	Bungoma	2003	79	31	98	29	3	3.0	35.7	***
	Butere-Mumias	2002	45	51	34	19	1	2.7		
	Butere-Mumias	2003	129	17	72	21	1	3.1	30.6	***
	Busia	2002	131	74	52	13	0	2.6		
	Busia	2003	136	110	47	7	0	2.4	7.1	*
	Kakamega	2002	271	51	44	54	0	3.0		
	Kakamega	2003	199	40	73	18	0	2.8	25.5	***
	Lugari	2002	48	5	3	4	0	2.9		
	Lugari	2003	58	18	13	1	0	2.5	7.9	**
	Teso	2002	93	38	13	6	0	2.4		
	Teso	2003	227	45	28	0	0	2.4	10.3	**
	Vihiga[z]	2003	96	9	26	19	0	2.3		
	Total	2002	762	309	221	147	1	2.8		
	Total	2003	850	316	385	95	4	2.7		

Z: Indicates districts assessed only once during the two years. [y]χ^2 = chi-square value; NS, *, **, ***, indicate not significant, significant at $P = 0.05$, $P = 0.01$, $P = 0.001$, respectively.

Table 6b. Plants under different severity score categories in various Siaya divisions during 2003 and 2004

		Severity score category [z,y]					Avg.		
Division	Year	1	2	3	4	5	score	χ^2	Significance
Boro	2003	58	62	142	8	0	2.7		
Boro	2004	41	104	152	3	0	2.6	8.6	**
Karemo	2003	61	52	94	3	0	2.7		
Karemo	2004	23	67	117	3	0	2.7	0.1	NS
Ugunja	2003	147	141	176	16	0	2.6		
Ugunja	2004	230	102	77	11	0	2.5	7.4	*
Ukwala	2003	64	83	77	16	0	2.6		
Ukwala	2004	95	56	52	6	1	2.6	2.7	NS
Uranga	2003	50	35	63	2	0	2.7		
Uranga	2004	36	140	89	26	9	2.6	29.0	***
Wagai	2003	36	54	116	4	0	2.7		
Wagai	2004	3	28	29	0	0	2.5	7.0	*
Yala	2003	76	45	87	29	3	2.9		
Yala	2004	14	47	83	6	0	2.7	23	***
Total	2003	492	472	755	78	3	2.7		
Total	2004	442	544	599	55	10	2.6		

[z] χ^2 indicates chi-square value.
[y] NS, *, **, *** indicate not significant, significant at $P = 0.05$, $P = 0.01$, $P = 0.001$, respectively.

4.1.6. Disease incidence

With the exception of Rift Valley province the CMD incidence in the region was moderate to high, averaging about 50% each year (Figures 12a and 12b). Cassava mosaic disease occurred in 94.1% of all fields sampled in 2002 and 96.3% of those surveyed in 2003. The overall mean incidence for all fields sampled was 48.4% in 2002 and 51.3% in 2003.

Frequencies of total CMD incidence for fields sampled were derived from whitefly- and cutting-borne incidences (Figures 13 and 14). All CMD incidence percentages resulted because data were combined for all regions. The greatest proportion of fields in both years fell within the 91% to 100% category for Siaya, and 71% to 80% category for western Kenya.

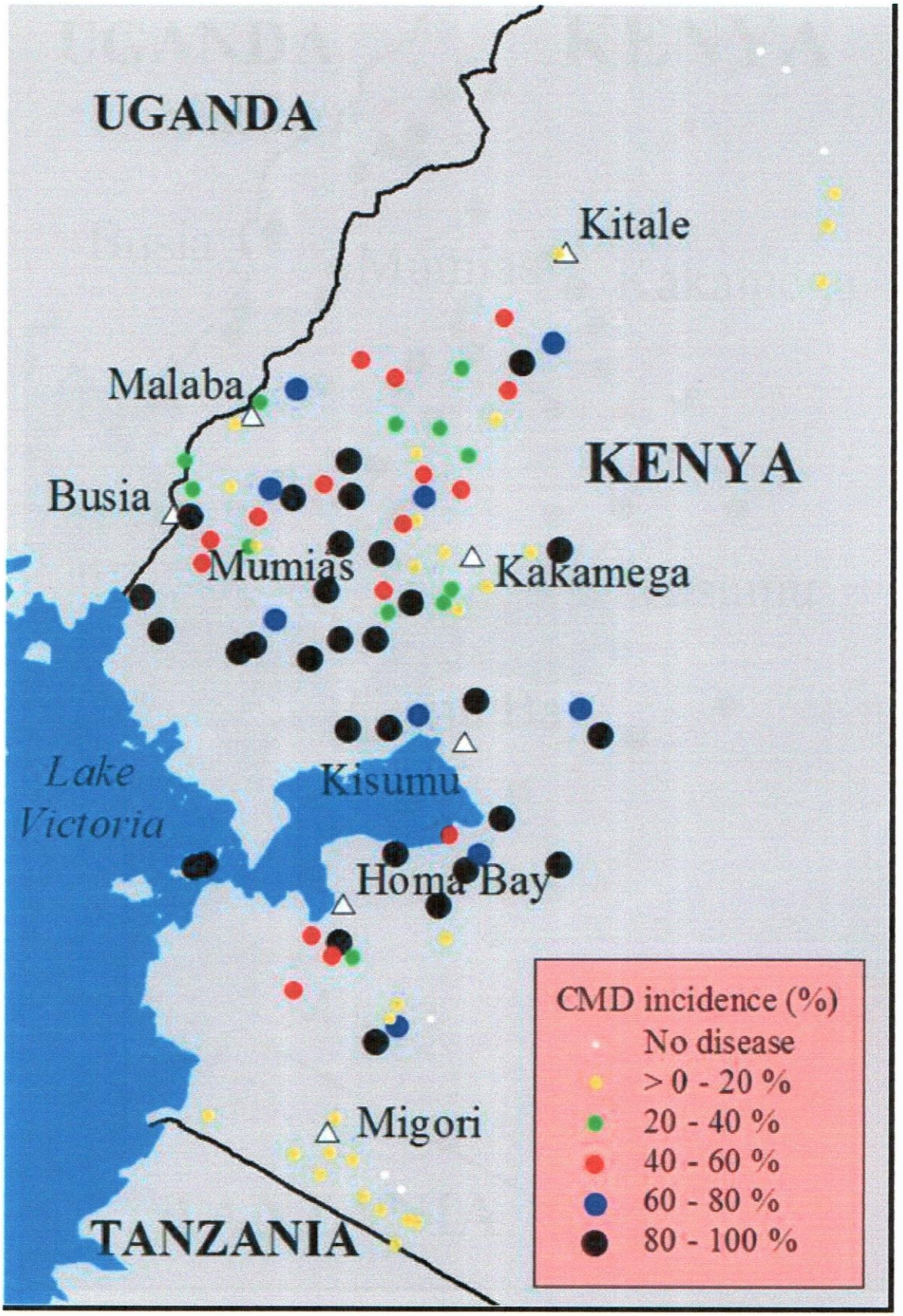


Figure 12a. Incidences of cassava mosaic disease in western Kenya during 2002

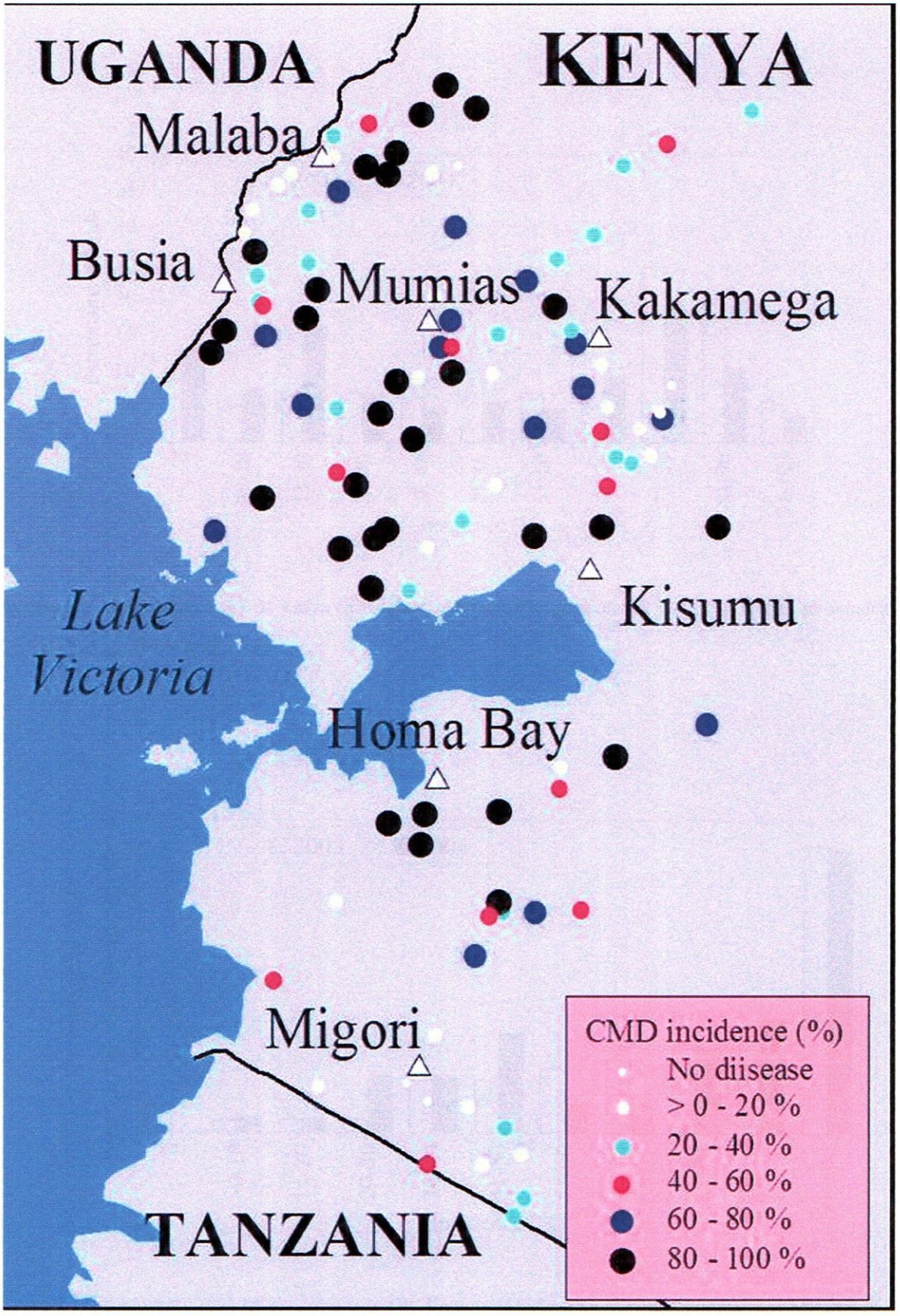


Figure 12b. Incidences of cassava mosaic disease in western Kenya during 2003

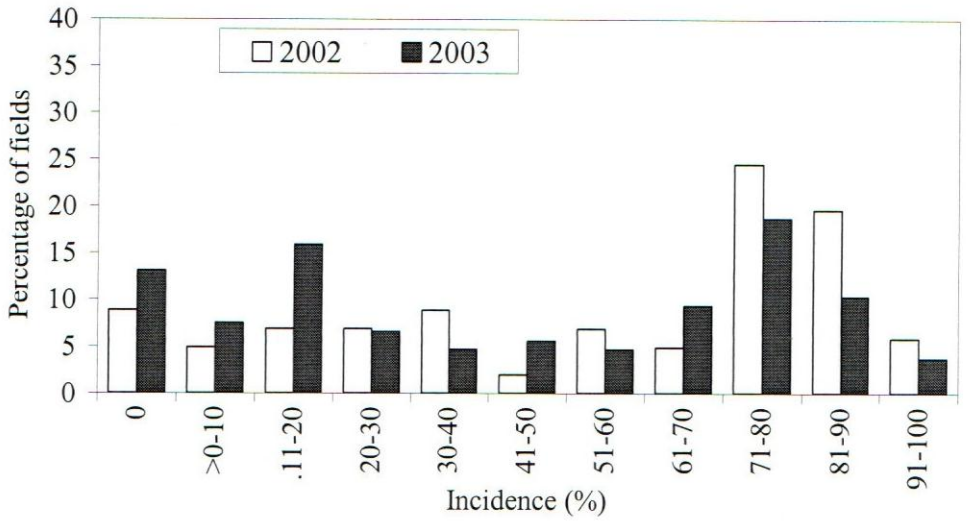


Figure 13. Frequency (%) of cassava mosaic disease incidences for cassava fields in western Kenya during 2002 and 2003

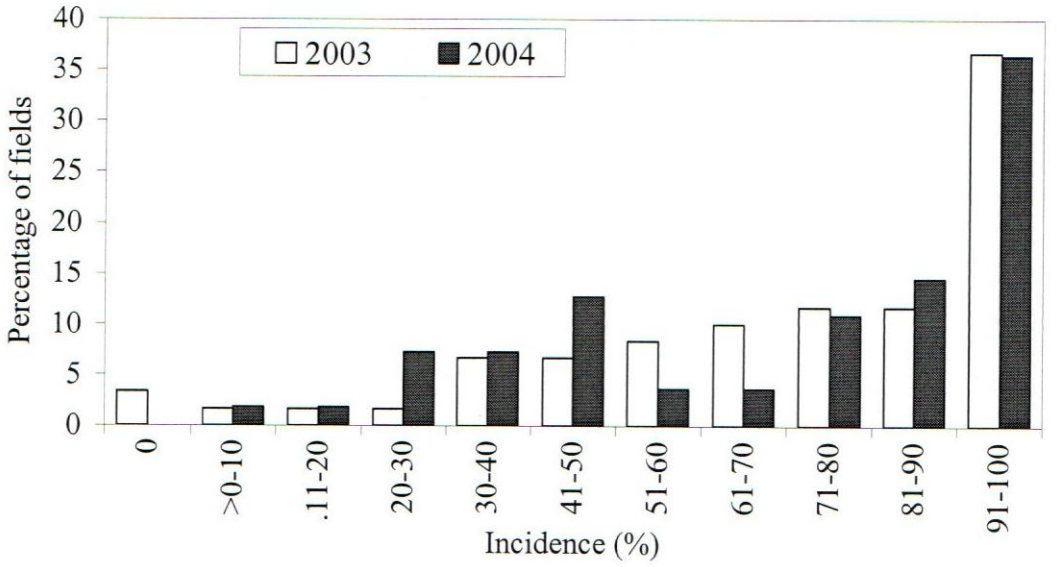


Figure 14. Frequency (%) of cassava mosaic disease incidences for cassava fields in Siaya District during 2003 and 2004

4.1.7. Infection type

In Siaya District, the incidence was almost over 70%; up to 75% of this resulted from cutting-borne infection. Infestation was higher in 2004 in all the divisions, except Ugunja and Ukwala (Table 7). Nyanza Province had the highest disease incidence; the proportion of the total incidence that was due to cutting-borne infection was high, ranging from 90% to 100% regardless of the province (Table 8). Whitefly-borne CMD incidences were generally low in comparison to the cutting-borne CMD incidences.

Table 7. Incidence of CMD and *B. tabaci* abundance on cassava in Siaya during 2003 and 2004

2003		Variable assessed [z]				
Division	Fields	TI [%] [y]	C [%]	W [%] (t) [x]	Whiteflies	Severity score
Boro	9	78.5	68.9	9.6 (36.9)	0.5	2.4
Karemo	7	71.0	59.5	11.4 (33.1)	0.4	2.3
Ugunja	16	69.4	47.1	22.3 (54.7)	1.0	2.5
Ukwala	8	73.3	58.8	14.6 (43.8)	2.4	2.6
Uranga	5	66.7	47.3	19.3 (45.6)	1.0	2.6
Wagai	7	82.9	75.2	7.6 (36.6)	0.6	2.7
Yala	8	68.3	52.5	15.8 (40.4)	0.7	3.0
Total	60	72.4	57.1	15.3	2.2	2.6
2004						
Boro	10	86.3a	84.0	2.3 (15.5)	33.3	2.3
Karemo	7	89.1a	89.1	0.0 (0)	10.8	2.6
Ugunja	14	45.2b	35.2	10.0 (16.8)	15.1	2.5
Ukwala	7	54.8b	42.4	12.4 (24.2)	4.1	2.5
Uranga	10	88.0a	80.0	8.0 (51.1)	47.2	2.6
Wagai	2	95.0a	95.0	0.0 (0)	3.5	2.6
Yala	5	90.7a	86.7	4.0 (35.8)	4.2	2.7
Total	55	71.0	65.1	5.1	16.44	2.5

[z]TI = total incidence, C = cutting infection, W = whitefly infection, Whiteflies = mean adult whiteflies on top five leaves.

[y]Values followed by no letter or the same letter within TI columns of each year are not significantly different at $P \leq 0.05$ (Mann-Whitney Wilcoxon statistic).

[x]Values in parenthesis refer to percentages expressed as multiple infection units (Gregory, 1948).

Table 8. Incidence of CMD and *B. tabaci* abundance in Western Kenya during 2002 and 2003

2002			Variable assessed [z]			
Province	District	Fields	TI [%][y]	C [%]	W [%](t) [x]	Whiteflies
Nyanza	Gucha	3	30.0 def	28.9	1.1 (1.6)	0.1
	Homabay	5	61.3 abcd	56.0	5.3 (12.8)	0.2
	Kisii	1	20.0 ef	10.0	10.0 (11.8)	0.1
	Kisumu	4	86.7 ab	76.7	10.0 (56.1)	0.4
	Kuria	10	7.7 f	7.0	0.7 (0.8)	0.1
	Migori	5	26.0 def	23.3	2.7 (3.6)	0.2
	Nyando	4	95.0 a	89.0	5.0 (60.6)	1.5
	Rachuonyo	6	88.3 ab	87.2	1.1 (9.0)	0.4
	Siaya	6	86.1 ab	79.4	6.7 (39.3)	1.1
	Suba	2	98.3 a	91.7	6.7 (164.6)	7.6
R. Valley	Marakwet	4	5.8 f	8.3	0.0 (0)	1.1
	T-Nzoia	2	30.0 def	30.0	0.0 (0)	0.1
	W-Pokot	2	0 f	0	0.0 (0)	0.4
Western	Bungoma	13	55.4 bcde	50.5	4.9 (10.4)	0.2
	Busia	9	51.5 bcde	46.7	4.8 (9.4)	0.3
	Butere-Mumias	5	70.0 abc	68.7	1.3 (4.2)	0.1
	Kakamega	14	35.5 cdef	32.6	2.9 (4.4)	0.1
	Lugari	2	20.0 ef	20	0.0 (0)	0.1
	Teso	5	38.0 cdef	36	2.0 (3.2)	0.1
2003						
Nyanza	Bondo	4	77.5 abc	76.7	0.8(3.5)	1.4
	Gucha	2	62.0 abcde	43.3	18.3(39)	0.8
	Homabay	5	83.6 ab	82.0	0.6(3.4)	0.0
	Kisumu	5	59.2 bcde	54.2	5(11.6)	0.5
	Kuria	8	26.7 ef	21.4	5.2(6.8)	0.1
	Migori	11	35.8 def	26.4	9.4(13.7)	0.2
	Nyando	1	100.0 a	100.0	0(0)	0.4
	Rachuonyo	4	44.2 bcdef	35.0	9.2(15.3)	0.4
	Siaya	8	80.0 ab	79.2	0.8(3.90	0.1
R. Valley	Nandi	4	14.2 f	14.2	0(0)	0.0
Western	Bungoma	8	67.1 abcd	65.8	1.3(3.9)	0.2
	Busia	10	51.7 bcde	50.4	1.3(2.7)	1.3
	Butere-Mumias	8	47.1 bcdef	43.3	3.7(6.7)	0.8
	Kakamega	11	43.3 cdef	37.3	6(10.1)	0.2
	Lugari	3	37.8 def	35.6	0.2(0.3)	0.0
	Teso	10	24.3 ef	24.3	0.3(0.4)	0.1
	Vihiga	5	36.0 def	29.3	6.7(10.0)	0.4

[z]TI = total incidence, C = cutting infection, W = whitefly infection, Whiteflies = mean adult whiteflies on top five leaves.

[y]Values followed by no letter or the same letter within TI columns of each year are not significantly different at $P \leq 0.05$ (Mann-Whitney Wilcoxon statistic).

[x]Values in parenthesis refer to percentages expressed as multiple infection units (Gregory, 1948).

4.1.8. Adult whitefly population

In Siaya District the average adult whiteflies per top five leaves were about 3 in 2003 and about 17 in 2004 (Table 7). Abundance of whiteflies on cassava plants in western Kenya was mostly low, averaging between 0 and 9 adult whiteflies per top five leaves (Table 8; Figures 15a and 15b). Pearson's correlation coefficient tests indicated positive correlations between CMD incidence and adult whiteflies; however, the correlation was only significant ($P<0.05$) in western Kenya survey of 2002. There was a significant positive correlation (0.46) between total CMD incidence and adult whiteflies, and an even stronger correlation (0.93) between whitefly-borne CMD incidence and adult whiteflies (Table 9).

Table 9. Correlation between incidence of cassava mosaic disease and number of adult whiteflies (*B. tabaci*) in western Kenya in 2002 [z]

Parameter 1	Parameter 2	Coefficient	P-value	Significance
CMD incidence total (C+W)	*B. tabaci* number	0.46	0.047	*
CMD whitefly-borne (transformed)	*B. tabaci* number	0.93	0.001	***

[z]*, *** indicate significance at $P = 0.05$, and $P = 0.001$, respectively. C = cutting infection, W = whitefly infection

4.1.9. Virus types in CMD affected plants in western Kenya

There were three main CMGs occurring in western Kenya, namely ACMV, EACMV and EACMV-UG (Table 10). The most frequently occurring CMG in all districts surveyed in each year, except for West Pokot in 2002, was EACMV-UG. *African cassava mosaic virus* was present in 10 and 7 districts in 2002 and 2003, respectively, and had some representation in all the three provinces. *East African cassava mosaic virus* was present in six and five districts in 2002 and 2003, respectively. It was absent in Rift Valley in both years and in Western province in the survey of 2003. Mixed infections were few, averaging about 10% in each year, with the combination of ACMV and EACMV-UG being the most common.

In Siaya District, leaf samples were only collected in 2004; of 27 positive samples, 24 (89%) were EACMV-UG in all the divisions, and similar to results of the western Kenya surveys where Siaya only had EACMV-UG in each year (Table 10). ACMV was present in only two fields in Boro division, and only one mixed infection of ACMV and EACMV-UG was observed in Yala division.

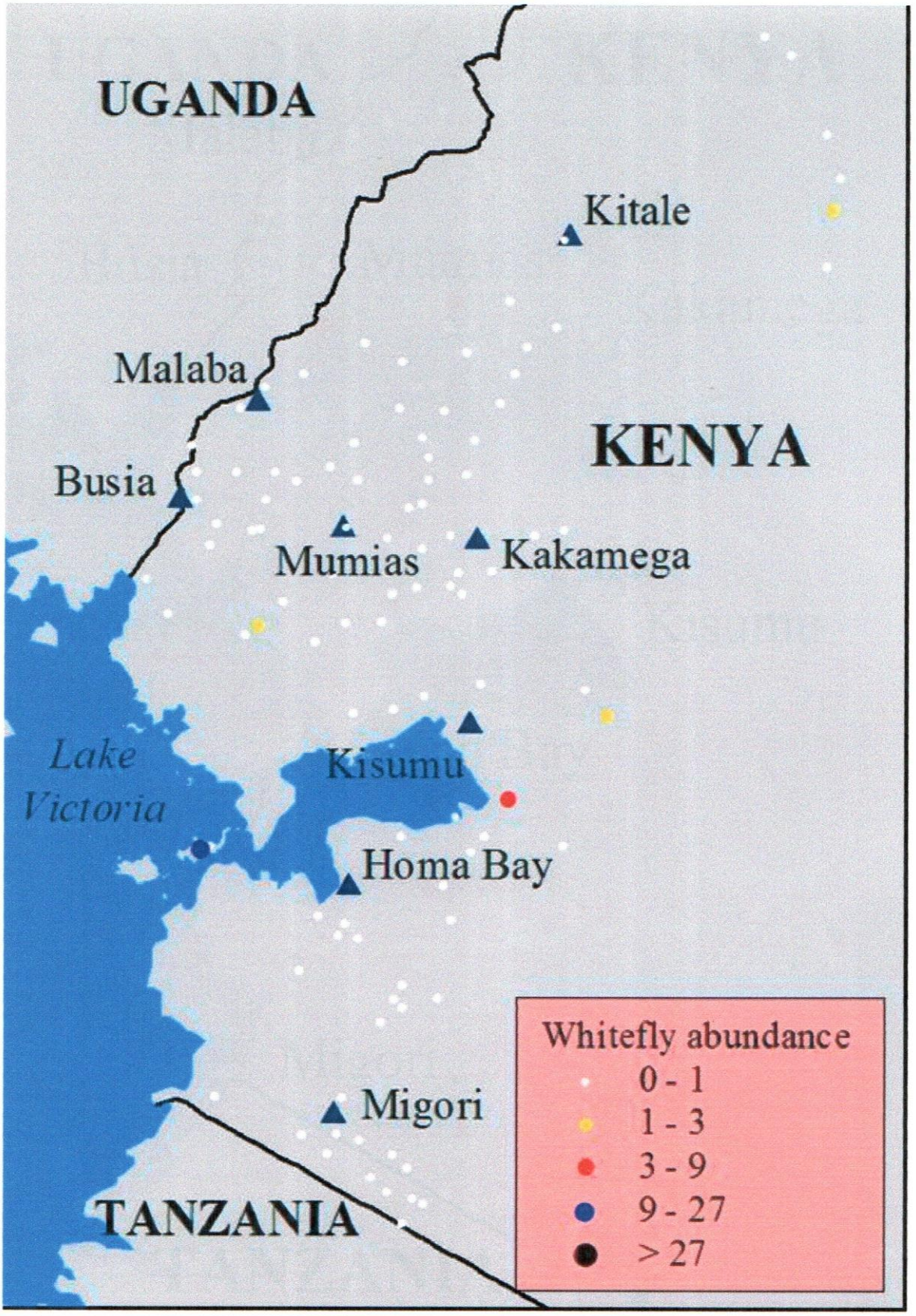


Figure 15a. Distribution of adult whitefly population in western Kenya during 2002

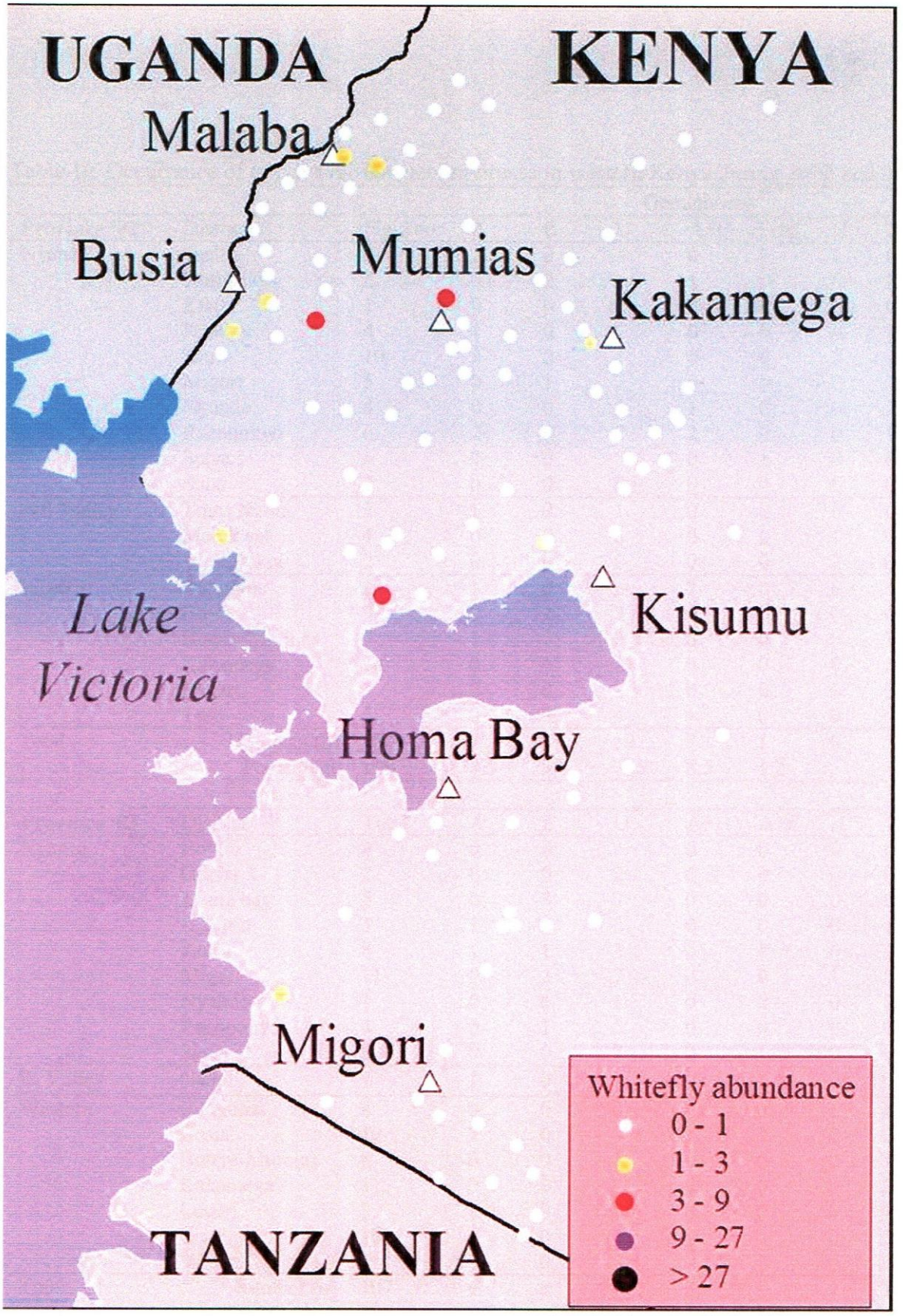


Figure 15b. Distribution of adult whitefly population in western Kenya during 2003

Table 10. Occurrence of cassava mosaic geminiviruses in western Kenya during 2002 and 2003

			Geminivirus [z]						
Province '02	District	Field no.	A	E	U	A+U	U+E	H	N
Nyanza	Gucha	3	1	0	1	0	0	1	0
	Homabay	5	0	2	2	1	0	0	0
	Kisii	1	0	0	1	0	0	0	0
	Kisumu	4	1	0	2	0	0	0	1
	Kuria	10	2	2	1	0	0	2	4
	Migori	5	0	1	2	0	0	0	2
	Nyando	4	0	0	2	1	0	0	1
	Rachuonyo	6	2	0	2	2	0	0	1
	Siaya	6	0	0	5	0	1	0	0
	Suba	2	0	0	2	0	0	0	0
Rift Valley	Trans Nzoia	2	1	0	1	0	0	0	0
	Marakwet	4	0	0	3	0	0	1	0
	West Pokot	2	0	0	0	0	0	2	0
Western	Bungoma	13	1	0	9	2	0	0	1
	Busia	9	0	2	7	0	0	0	0
	Butere-Mumias	5	1	1	2	0	0	0	1
	Kakamega	14	0	0	11	0	0	0	3
	Lugari	2	0	0	2	0	0	0	0
	Teso	5	0	0	4	1	0	0	0
Total	Numbers (n)	102	7	8	59	7	1	6	14
	Percentage	100	8.5	9.8	72.0	8.5	1.2		

Province '03	District	Total	A	E	U	A+U	A+E	H	B
Nyanza	Bondo	4	0	0	4	0	0	0	0
	Gucha	2	0	0	2	0	0	0	0
	Homa bay	5	0	3	2	0	0	0	0
	Kisumu	5	1	0	3	0	0	0	1
	Kuria	8	1	1	3	0	0	0	3
	Migori	11	0	3	7	0	0	1	0
	Nyando	1	0	0	1	0	0	0	0
	Rachuonyo	4	0	1	3	0	0	0	0
	Siaya	8	0	0	7	0	1	0	0
R. Valley	Nandi	4	1	0	3	0	0	0	0
Western	Bungoma	8	0	0	6	0	0	1	1
	Busia	10	2	0	4	2	0	0	2
	Butere-Mumias	8	0	0	7	0	0	0	1
	Kakamega	11	0	0	9	0	0	0	2
	Lugari	3	1	0	1	0	0	0	1
	Teso	10	0	0	4	1	0	0	5
	Vihiga	5	0	0	5		0	0	0
Total	Number (n)	107	6	8	71	3	1	2	16
	Percentage	100	6.7	9.0	79.8	3.4	1.1		

[z] A = *African cassava mosaic virus* (ACMV). E = *East African cassava mosaic virus* (EACMV). U = *East African cassava mosaic virus* – Uganda (EACMV-UG). H = All plants healthy, no sample picked. N = No result.

4.1.10. Germplasm diversity

A wide diversity of cultivars was encountered during the surveys (Table 11). Both local landraces and improved resistant varieties were present in the region, although local varieties predominated, while resistant varieties were more in Western province. In northern Nyanza, Adhiambolera was most common, while Ong'ielo and Obarodak were preferred in southern Nyanza. In Kisii-Nyanza, Mwita Machera and Waite were the most widely cultivated varieties.

Table 11. Prevalence (%) of predominant cassava varieties in plantings assessed in western Kenya during 2002 and 2003, and number of fields where present [z]

	Province and year							
	Nyanza		Rift Valley		Western		Total western Kenya	
Variety	2002	2003	2002	2003	2002	2003	2002	2003
Local	100(46)	97.9(47)	37.5(3)	100(4)	79.2(38)	80(44)	85.3(87)	88.8(95)
Improved	0(0)	2.1(1)	62.5(5)	0(0)	20.8(10)	20(11)	14.7(15)	11.2(12)

[z] Values outside parenthesis indicate prevalence percentages, whereas those inside parenthesis indicate number of fields with local or improved varieties

4.2. Experiment 2. Measurement of CMD Inoculum Pressure in Siaya District

4.2.1. Disease incidence

The total incidence at each site was generally low and averaged less than 40% (Table 12). In the November 2002 to June 2003 (2002 to 2003) season the incidence was highest at Ukwala and Karemo, while in the October 2003 to May 2004 (2003 to 2004) season it was highest at Ukwala. Incidences for Bukalasa 11 were higher than those for Migyera. There were clear differences in the proportion of plants that became affected by cassava mosaic disease (CMD) (Figure 16). Generally the disease spread was faster in Bukalasa 11 than in Migyera at all sites.

All plants were initially healthy (CMD-free) at the onset and hence there was no incidence at one month after planting (MAP). However, from four MAP in the 2002 to 2003 season, and three MAP in the 2003 to 2004 season, respectively, Migyera began to develop symptoms that were mild and characterized by mosaic, but no leaf distortion. At Ukwala, Karemo and Yala in the 2002 to 2003 season, and at Karemo in the 2003 to 2004 season there was no disease incidence. For Bukalasa 11, by two MAP plants had become infected at all sites, except at Yala in the 2002 to 2003 season where first infections were recorded at 6 MAP. At Karemo in the 2003 to 2004 season infection began increasing at four MAP.

The rate of cassava mosaic disease increase was generally greatest between five and six MAP, although new infections continued to occur up to the end of the recording period for Bukalasa 11 (Figure 16).

Table 12. Final disease incidence (%) for Migyera and Bukalasa 11 in four divisions of Siaya during the 2002 to 2003 and 2003 to 2004 seasons

		Variety[z]		
Year	Division	Migyera	Bukalasa 11	Mean
2002 to 2003	Ukwala	0.0	48.0	24.0a
	Ugunja	0.0	22.0	11.0b
	Karemo	2.0	46.0	24.0a
	Yala	0.0	12.0	6.0b
	Mean	0.5b	32.0a	
	Division $LSD_{0.05}$	Significant		
	Variety $LSD_{0.05}$	Significant		
	Interaction $LSD_{0.05}$	NS		
2003 to 2004	Ukwala	4.0	68.0	36a
	Ugunja	6.0	42.0	24b
	Karemo	0.0	6.0	3c
	Yala	2.0	4.0	3c
	Mean	3.0b	30.0a	
	Division $LSD_{0.05}$	Significant		
	Variety $LSD_{0.05}$	Significant		
	Interaction $LSD_{0.05}$	NS		

[z] Values followed by the same letter within each main factor of each season are not significantly (NS) different at $P \leq 0.05$.

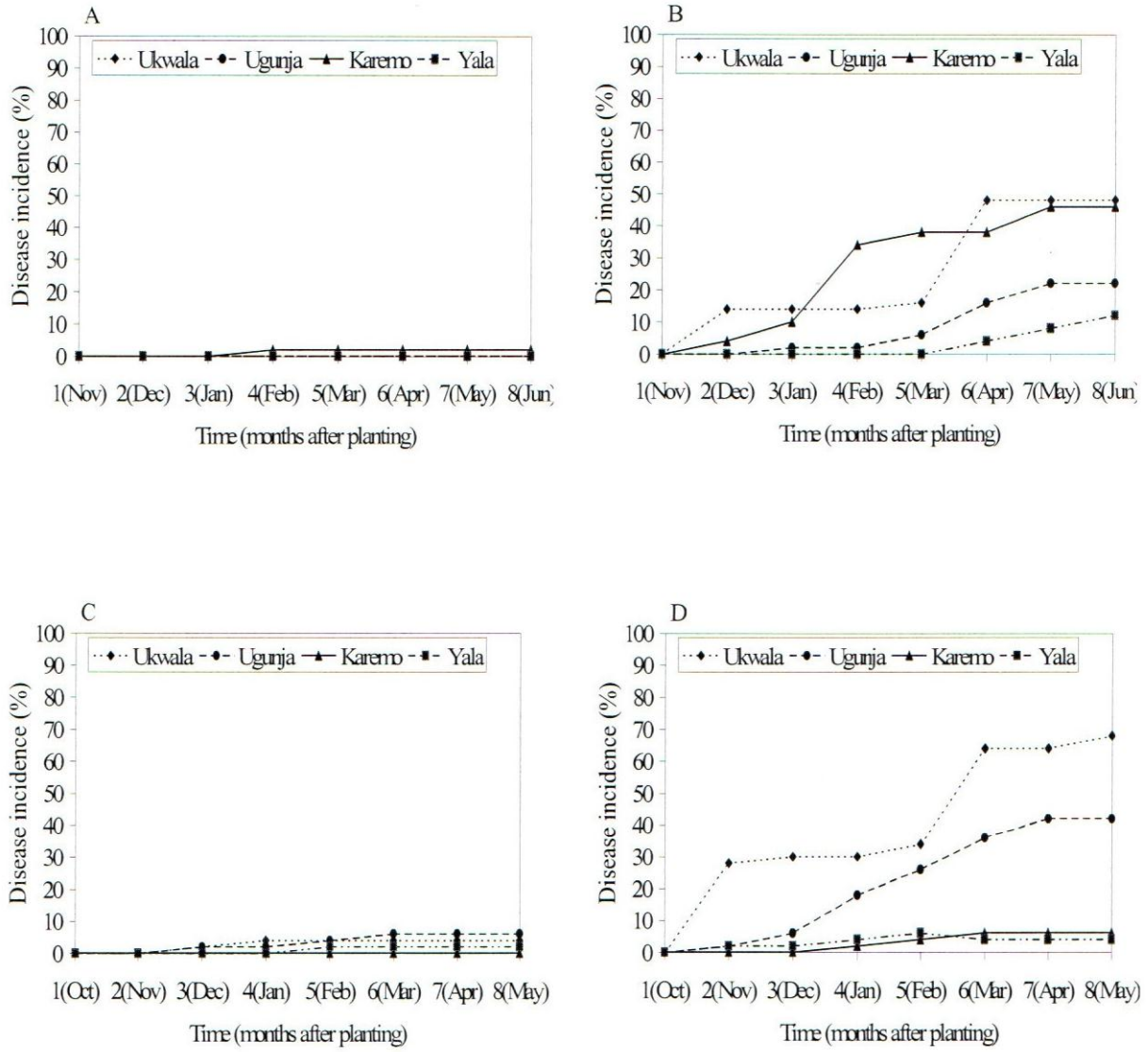


Figure 16. Incidence of cassava mosaic disease for: Migyera in 2002 to 2003 (A), Bukalasa 11 in 2002 to 2003 (B), Migyera in 2003 to 2004 (C), and Bukalasa 11 in 2003 to 2004 (D), grown in four divisions of Siaya District

4.2.2. Disease (symptom) severity

Division and interaction did not have a significant effect on CMD severity in both seasons (Table 13). Variety on the other hand only had a significant effect on severity in 2003 to 2004. Migyera plants were mostly clean and the severity indices were 1.0 (baseline) (Table 13). The mean severity indices were 2.6 in 2002 to 2003, and 2.2 in 2003 to 2004 for Bukalasa 11.

Table 13. Mean severity score of diseased plants for Migyera and Bukalasa 11 varieties in four divisions of Siaya District during the 2002 to 2003 and 2003 to 2004 seasons

		Variety [z,y]		
Year	Division	Migyera	Bukalasa 11	Mean
2002 to 2003	Ukwala	-	2.6	2.6
	Ugunja	-	2.7	2.7
	Karemo	2.6	2.4	2.5
	Yala	-	2.4	2.4
	Mean	2.6	2.6	2.6
	Division $LSD_{0.05}$		NS	
	Variety $LSD_{0.05}$		NS	
	Interaction $LSD_{0.05}$		NS	
	CV(%)		13.7	
2003 to 2004	Ukwala	2.2	2.2	2.2
	Ugunja	2.0	2.3	2.2
	Karemo	-	2.2	2.2
	Yala	2.0	2.2	2.1
	Mean	2.1b	2.2a	
	Division $LSD_{0.05}$		NS	
	Variety $LSD_{0.05}$		0.1	
	Interaction $LSD_{0.05}$		NS	
	CV (%)		28.7	

[z] Variety values not followed by a letter in 2002 to 2003, or followed by the same letter in 2003 to 2004 are not significantly different at $P \leq 0.05$.

[y] Division and interaction values not followed by a letter within each season are not significantly (NS) different at $P \leq 0.05$.

Chi-square values for comparison of severity indices of Bukalasa 11 plants gave small and insignificant differences, except at Ugunja in 2002 to 2003, when there was a significant difference from five to six MAP. Migyera plants were not subjected to chi-square analysis since its severity indices were only baseline. All plants were initially healthy and had no disease at 1 MAP. However for Bukalasa 11 in all seasons and divisions, except Yala in 2002 to 2003, there were plants showing CMD symptoms and the severity increased progressively with time. At the other divisions, however, severity remained relatively constant and was mostly 2.0, or slightly higher until the end of the experiment (Figure 17). Migyera did not develop any symptoms at Ukwala, Karemo and Yala in the 2002 to 2003 season and at Karemo in the 2003 to 2004 season. Generally, there was a gradual increase in severity over time. The highest CMD severity indices of 3.3 in the 2002 to 2003 season, and 2.8 in the 2003 to 2004 season were recorded in Bukalasa 11 at Ugunja and Ukwala, respectively (Figure 17).

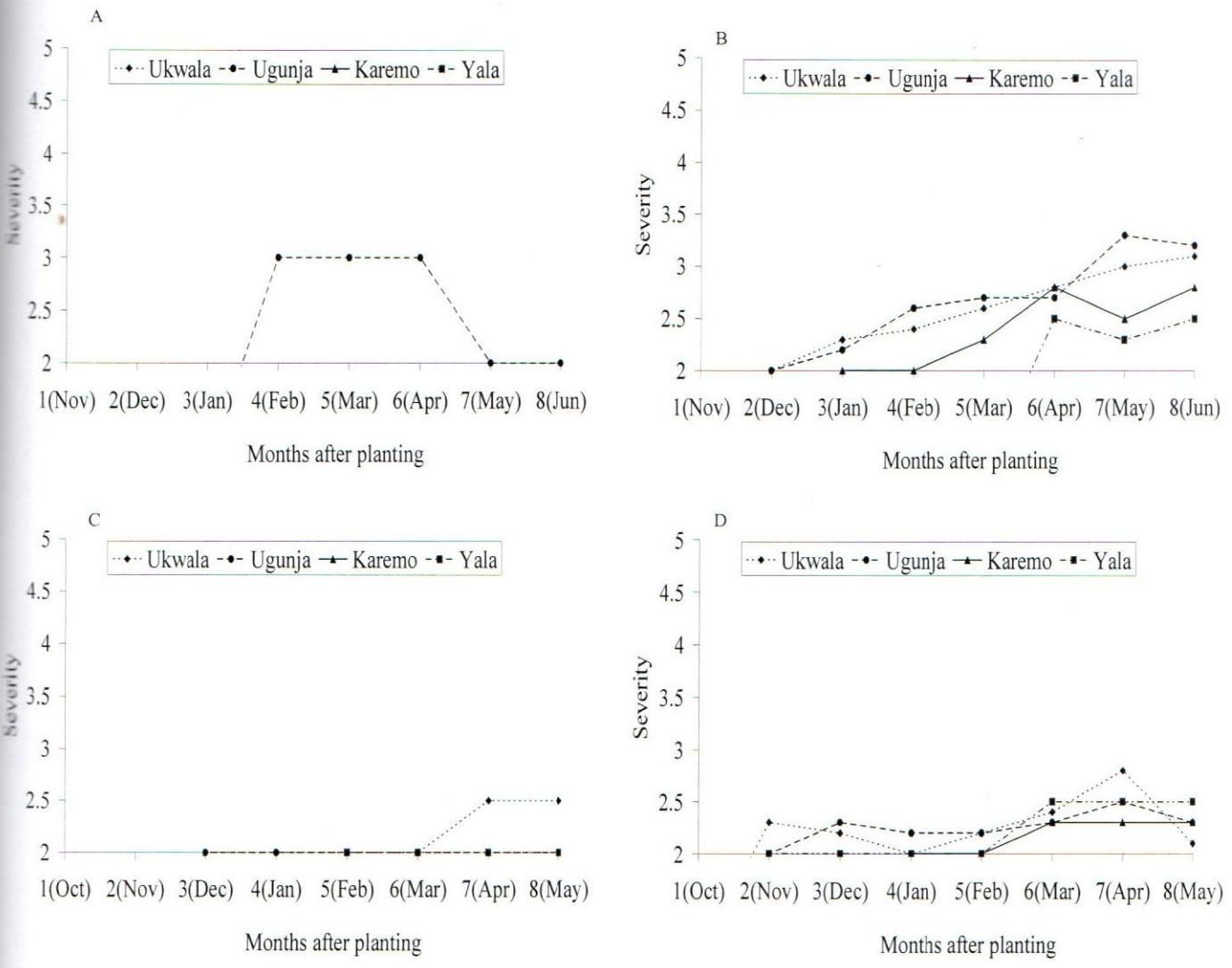


Figure 17. Severity indices of cassava mosaic disease for: Migyera in 2002 to 2003 (A), Bukalasa 11 in 2002 to 2003 (B), Migyera in 2003 to 2004 (C), and Bukalasa 11 in 2003 to 2004 (D), grown in four divisions of Siaya District

4.2.3. Number of adult whiteflies

The number of adult whiteflies was generally low and mostly ranged from 1 to 3 per plant throughout the experiment in the different divisions. There were small, but insignificant differences in numbers among divisions for both seasons (Table 14).

There was a significant effect of variety on number of adult whiteflies in the second (2003 to 2004) season. The averages were 2.4 and 1.4 for Migyera and Bukalasa 11, respectively in 2002 to 2003, and 3.3 and 1.2 for Migyera and Bukalasa 11, respectively in 2003 to 2004. Migyera generally had a higher whitefly population than Bukalasa 11 (Table 14). Number of adult whiteflies was generally greatest between 4 and 5 MAP for each variety in each season, after which the population decreased (Figure 18).

Table 14. Number of adult whiteflies for Migyera and Bukalasa 11 varieties in four divisions of Siaya District during the 2002 to 2003 and 2003 to 2004 seasons

		Variety [z,y]		
Year (season)	Division	Migyera	Bukalasa 11	Mean
2002 to 2003	Ukwala	2.9	3.0	3.0
	Ugunja	2.5	0.6	1.6
	Karemo	0.9	0.3	0.6
	Yala	3.2	1.5	2.4
	Mean	2.4	1.4	
	Division $LSD_{0.05}$	NS		
	Variety $LSD_{0.05}$	NS		
	Interaction $LSD_{0.05}$	NS		
	CV (%)	65.5		
2003 to 2004	Ukwala	4.7	1.9	3.3
	Ugunja	2.8	1.0	1.9
	Karemo	2.0	0.6	1.3
	Yala	3.6	1.1	2.4
	Mean	3.3	1.2	
	Division $LSD_{0.05}$	NS		
	Variety $LSD_{0.05}$	21		
	Interaction $LSD_{0.05}$	NS		
	CV (%)	59.2		

[z] Variety values not followed by a letter in 2002 to 2003 or followed by the same letter in 2003 to 2004 are not significantly different at $P \leq 0.05$.

[y] Division and interaction values not followed by a letter within each season are not significantly (NS) different at $P \leq 0.05$.

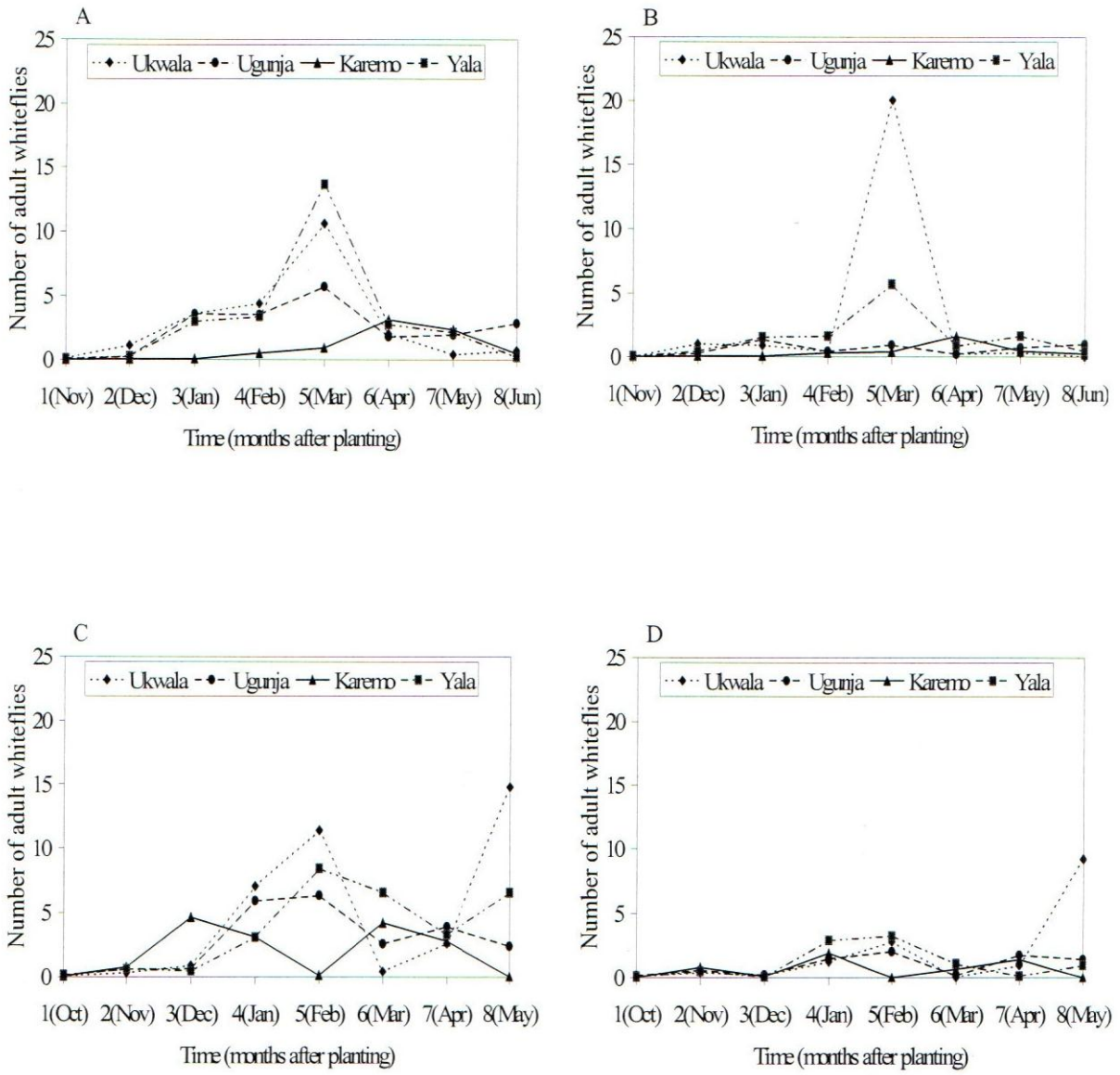


Figure 18. Abundance of adult whiteflies for: Migyera in 2002 to 2003 (A), Bukalasa 11 in 2002 to 2003 (B), Migyera in 2003 to 2004 (C), and Bukalasa 11 in 2003 to 2004 (D), grown in four divisions of Siaya District

4.2.4. Inoculum pressure

The inoculum availability index (S) at each trial site (division) was lowest at Ugunja and Karemo in the 2002 to 2003 season when S was 0. Availability index was highest (33.9) at Karemo in the 2003 to 2004 season (Table 15).

Table 15. Inoculum availability index for the different divisions of Siaya District during the 2002 to 2003 and 2003 to 2004 seasons

	Growing season	
Division	November 2002 to June 2003	October 2003 to May 2004
Ukwala	18.0	11.3
Ugunja	0	2.4
Karemo	0	33.9
Yala	0.2	1.5

4.2.5. Characterization of CMGs using RFLP and virus specific primers

Eight of the 14 samples produced amplification products with universal primers UNIF and UNIR (Figure 19a). The band distinction of the fragment lengths produced on digestion with the restriction enzyme *Eco*RV showed a positive reaction for both *East African cassava mosaic virus* (EACMV) and *East African cassava mosaic virus*-Uganda (EACMV-UG) in seven samples, and one had a mixed infection of *African cassava mosaic virus* (ACMV) and EACMV/EACMV-UG (Figure 19b). *Eco*RV does not distinguish the two viruses.

However following digestion with *Mlu*I, it was established that seven of the samples had EACMV-UG only, and the mixed infection was ACMV and EACMV-UG (Figure 19c). In Ugunja division, the plants for Bukalasa 11 were infected by EACMV-UG and the mixed infection was for Adhiambolera (Table 16).

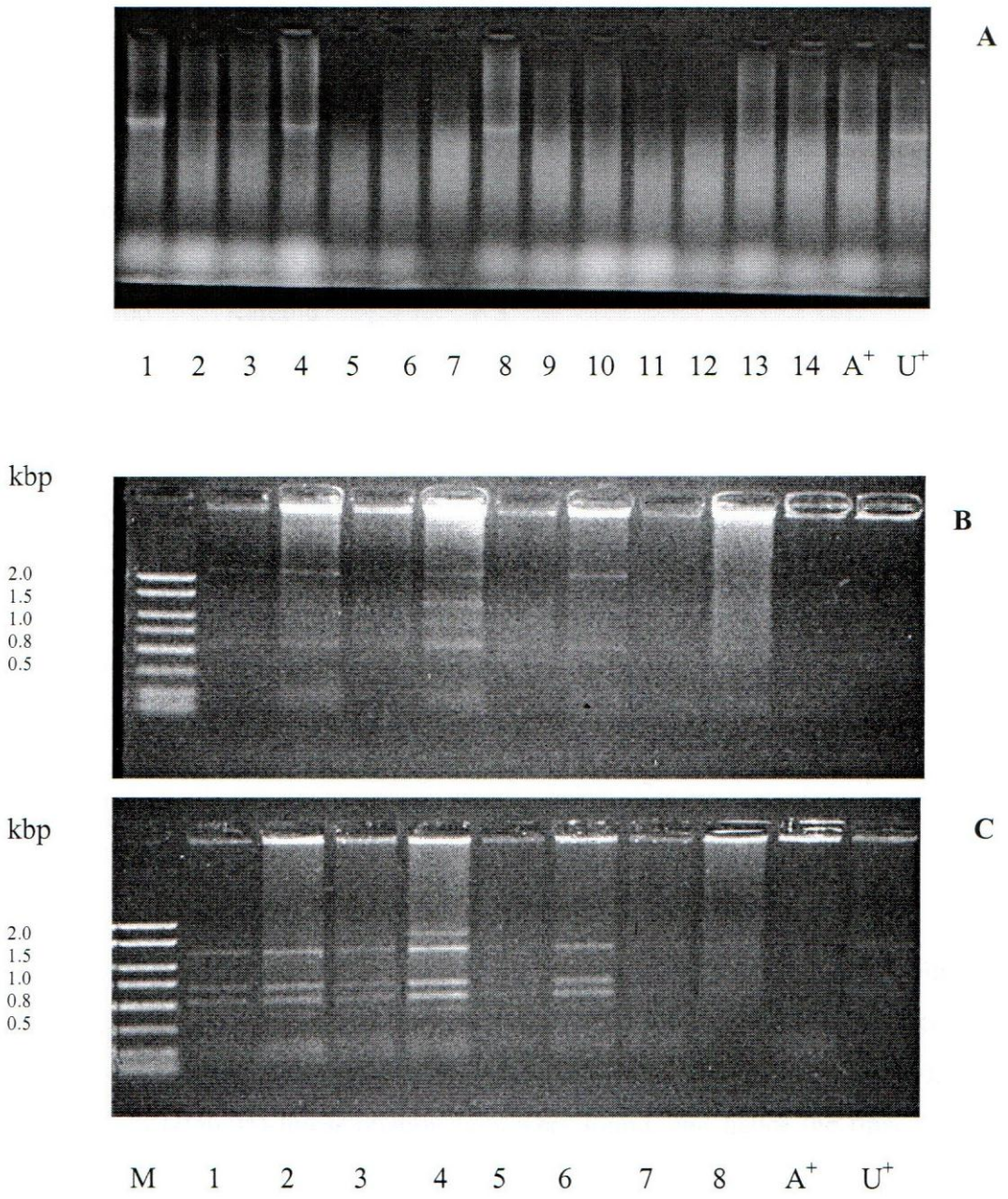


Figure 19. Gel electrophoresis of polymerase chain reaction DNA products, amplified using universal oligonucleotide primers for cassava mosaic gemiviruses (A), *Eco*RV (B), and *Mlu*I (C), where M = molecular marker (DNA ladder), A^+ = positive control for *African cassava mosaic virus*, and U^+ = positive control for *East African cassava mosaic virus*-Uganda.

Table 16. Virus identity for CMD-infected samples collected from different divisions and varieties at 6 MAP during the 2002 to 2003 season

Sample number [x]	Division	Variety	Attribute [z]			
			Infection type	Universal primers	*Eco*RV	*Mlu*I
1	Karemo	Bukalasa 11	W3	+	U/E	U
2	Karemo	Bukalasa 11	W4	+	U/E	U
3	Karemo	Karemo [y]	W3	+	U/E	U
4	Ugunja	Adhiambolera [y]	C3	+	A/U/E	U
6	Ugunja	Bukalasa 11	W3	+	U/E	U
8	Yala	Bukalasa 11	W3	+	U/E	U
13	Ukwala	Bukalasa 11	W4	+	U/E	U
14	Ukwala	Adhiambolera [y]	C3	+	U/E	U

[z] C = cutting infection, W = whitefly infection, A = *African cassava mosaic virus*, E = *East African cassava mosaic virus*, U = *East African cassava mosaic virus*–Uganda.

[y] Samples were from plants in surrounding fields, but not from the trial sites.

[x] Sample numbers between 1 and 14 that are not shown did not give amplification products with universal primers.

4.2.6. Prediction of CMD incidence using whitefly abundance and inoculum availability

Multiple linear regression analyses were run to investigate relationships between final disease incidence versus adult whitefly abundance and inoculum availability index. No statistically significant ($P>0.05$) linear relationships were found, and hence the final incidence could not be predicted from a linear combination of the independent variables.

4.3. Experiment 3. Effects of CMD and Variety on Growth and Yield of Cassava

4.3.1. Disease (symptom) severity

Diseased cuttings for all the three varieties expressed cassava mosaic disease (CMD) symptoms, whereas healthy cuttings showed no symptoms (Table 17). Some Migyera cuttings from infected stems sprouted with no visible symptoms and were replaced with others from the back-up nursery; a few plants also had stems that started out diseased, but ended up not showing visible CMD symptoms on the leaves. Average severity index of diseased plants increased progressively with time from 2.0 at 1 month after planting (MAP) to a final average index of 2.7 at 10 MAP.

Variety, as well as disease status, had a significant ($P<0.05$) effect on the severity index of plants at each time of assessment (Table 17). Bukalasa 11 was the most severely affected variety, followed by Karemo and then Migyera. Severity increased with time for Bukalasa 11 and Karemo, but remained constant for Migyera. There was a significant ($P<0.05$) disease status by variety interaction effect on mean symptom severity at 3, 7 and 10 MAP (Table 17).

The number of plants under the different severity index categories was significantly ($P<0.05$) different for Bukalasa 11 and Karemo, at each of the three times of assessment (Table 18). Migyera was not considered for chi-square analysis, because its diseased plants were only of category 2.0-severity index.

Table 17. Effect of disease status and variety on CMD severity index at Ugunja

Time of assessment (months after planting)	Variety	Disease status [z, y]	
		Healthy	Diseased
1	Migyera	1.0	2.0
	Bukalasa 11	1.0	2.0
	Karemo	1.0	2.0
	Mean	1.0	2.0
	Variety $LSD_{0.05}$		NS
	CV (%)		0
3	Migyera	1.0	2.0b
	Bukalasa 11	1.0	2.6a
	Karemo	1.0	2.1b
	Mean	1.0	2.3
	Variety $LSD_{0.05}$		0.21
	CV (%)		4.01
7	Migyera	1.0	2.0a
	Bukalasa 11	1.0	3.3c
	Karemo	1.0	2.4b
	Mean	1.0	2.6
	Variety $LSD_{0.05}$		0.13
	CV (%)		2.20
10	Migyera	1.0	2.0a
	Bukalasa 11	1.0	3.7c
	Karemo	1.0	2.5b
	Mean	1.0	2.7
	Variety $LSD_{0.05}$		0.30
	CV (%)		4.85

[z] Disease status values not followed by a letter or followed by the same letter within each time of assessment are not significantly different (NS) at $P \leq 0.05$.

[y] Only diseased plants were analysed, as is the normal practice for these kinds of trials.

Table 18. Plants under different severity score categories at three times of assessment of Bukalasa 11 and Karemo varieties

Time of assessment (months after planting)	Variety	Severity score category [z]			
		2	3	4 to 5	χ^2
3	Bukalasa 11	27	32	1	23.9 ***
3	Karemo	56	9	0	
7	Bukalasa 11	4	35	21	48.2 ***
7	Karemo	39	25	1	
10	Bukalasa 11	4	9	47	78.4 ***
10	Karemo	30	34	12	

[z] χ^2 indicates chi-square value; *** indicates significant at $P = 0.001$.

4.3.2. Performance of growth variables

(a) Plant height

Both disease status and variety had a significant ($P<0.5$) effect on height of plants (Figure 20). Considering all varieties at 10 MAP, there was a significant difference ($P<0.05$) in the final heights of 138.6 cm and 107.5 cm for healthy and diseased cassava plants, respectively. Disease had a negative effect on plant height at 3, 7 and 10 MAP, and consistently caused cassava plants to not grow as tall as the healthy ones (Figure 20).

At 3 MAP, Migyera was significantly ($P<0.5$) shorter than the other two varieties in both healthy and diseased plants. At 7 MAP, healthy Karemo was significantly ($P<0.5$) taller than healthy Bukalasa 11 and healthy Migyera that were not significantly ($P>0.5$) different from each other; diseased plants were not significantly different among varieties. Differences in height among varieties were significant at 10 MAP with an average of 253.1 cm for Karemo, 188.6 cm for Bukalasa 11, and 159.9 cm for Migyera (Figure 20). Generally at 10 MAP, Karemo had the tallest plants for both diseased and healthy plants, whereas Migyera had the shortest. There was no significant ($P>0.5$) disease status by variety interaction effect on height of plants (Figure 20).

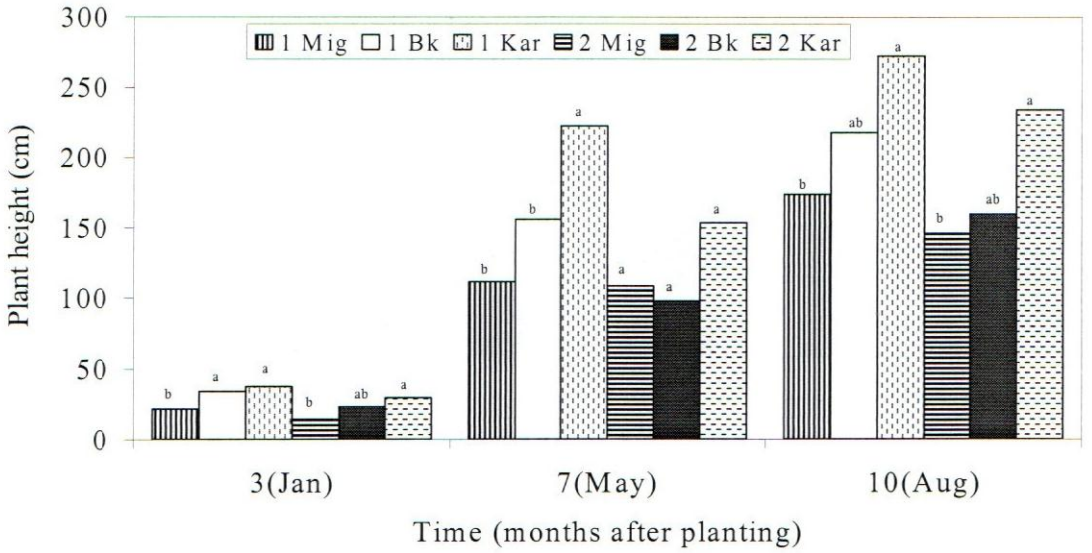


Figure 20. Height per plant at 3, 7 and 10 months after planting. 1 indicates healthy and 2 indicates diseased. Mig = Migyera, Bk = Bukalasa 11 and Kar = Karemo. Bars marked by the same letter within each time are not significantly different (NS) at $P \leq 0.05$.

(b) Stem circumference

Disease status had a significant effect on stem circumference of plants (Figure 21). Considering all varieties at 10 MAP, there was a significant difference ($P<0.05$) in the final stem circumference of 8.3 cm and 6.6 cm for healthy and diseased plants, respectively. Disease had a negative effect on stem circumference of plants at 3, 7 and 10 MAP, and consistently caused plants to develop smaller circumferences (Figure 21).

At 3 MAP, there was no significant difference ($P>0.05$) in circumferences of the three varieties for both diseased and healthy plants. At 7 MAP and 10 MAP, there was no significant ($P>0.05$) difference among the varieties for healthy plants; however, for diseased plants at 7 MAP, Migyera stems were significantly ($P<0.05$) thicker than those of Bukalasa 11, while Karemo's stems were not significantly different from those of the other varieties. At 10 MAP, diseased Bukalasa 11 stems were significantly different from those of diseased Karemo. Stem circumferences of diseased varieties at 10 MAP were 8.1 cm for Karemo, 6.6 cm for Bukalasa 11, and 7.6 cm for Migyera. There was no significant ($P>0.05$) disease status by variety interaction effect on stem circumference of plants.

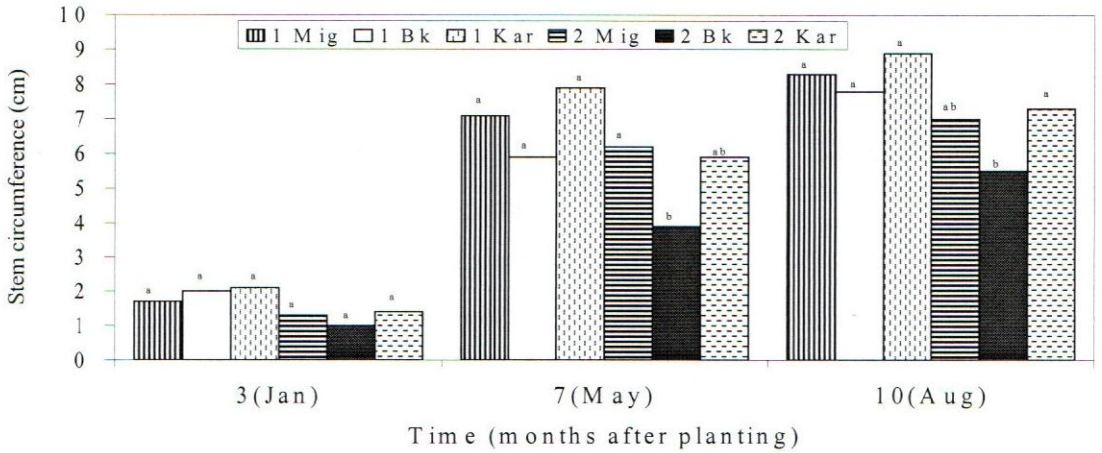


Figure 21. Stem circumference per plant at 3, 7 and 10 months after planting. 1 indicates healthy and 2 indicates diseased. Mig = Migyera, Bk = Bukalasa 11 and Kar = Karemo. Bars marked by the same letter within each time are not significantly different (NS) at $P \leq 0.05$.

(c) Number of stems

The average number of total stems for the three varieties across disease states was 2 (Table 19). The number of stems did not change with time, but remained the same at 3, 7 and 10 MAP. Considering diseased plants, the number of stems showing CMD symptoms differed amongst varieties, although the difference was not significant ($P>0.05$). For Migyera and Karemo, half the number of stems was diseased, while for Bukalasa 11 all stems were diseased (Table 19).

4.3.3. Cassava biomass and tuberous root yields

(a) Biomass

Disease status had a significant ($P<0.05$) effect on biomass production; healthy plants yielded higher (an average of 2.5 kg/plot) than diseased plants (an average of 1.7 kg/plot) (Table 20). However the biomass yield was not affected by disease status in Migyera. Variety also had a significant ($P<0.05$) effect on biomass production; Bukalasa 11 yielded significantly ($P<0.05$) lower biomass than the other two varieties (Table 20). The effect of interaction between disease status and variety on biomass production was significant ($P<0.05$). Healthy Karemo yielded the highest biomass, which was statistically ($P<0.05$) different from that of Bukalasa 11 and its diseased counterparts.

Table 19. Effect of disease status and variety on number of total and finally diseased stems per plant at 3, 7 and 10 months after planting

Time of assessment (months after planting), stem type	Variety	Disease status [z, y]		Mean
		Healthy	Diseased	
3, Total	Migyera	1	2	2
	Bukalasa 11	2	2	2
	Karemo	2	2	2
	Mean	2	2	2
3, Diseased	Migyera	-	1	1
	Bukalasa 11	-	2	2
	Karemo	-	1	1
	Mean	-	1	1
7, Total	Migyera	1	2	2
	Bukalasa 11	2	2	2
	Karemo	2	2	2
	Mean	2	2	2
7, Diseased	Migyera	-	1	1
	Bukalasa 11	-	2	2
	Karemo	-	1	1
	Mean	-	1	1
10, Total	Migyera	1	2	2
	Bukalasa 11	2	2	2
	Karemo	2	2	2
	Mean	2	2	2
10, Diseased	Migyera	-	1	1
	Bukalasa 11	-	2	2
	Karemo	-	1	1
	Mean	-	1	1

[z] - indicates no finally diseased stems

[y] Values not followed by a letter within each factor and for each time of assessment are not significantly different at $P \leq 0.05$.

Table 20. Effect of disease status and variety on biomass (kg/plant) in Siaya District

Variety	Initial disease status [z]		Mean
	Healthy	Diseased	
Migyera	2.3h	2.6h	2.4a
Bukalasa 11	1.3ij	0.9j	1.1b
Karemo	4.0g	1.7hij	2.8a
Mean	2.5d	1.7e	
Disease status $LSD_{0.05}$	0.6		
Variety $LSD_{0.05}$	0.9		
Interaction $LSD_{0.05}$	1.0		
CV (%)	31.4		

[z] Values followed by the same letter within each factor are not significantly different (NS) at $P \leq 0.05$.

(b) Number of tuberous roots

There was a significant ($P<0.05$) effect of disease status on number of marketable tuberous roots, which were about 5 and about 3 for healthy and diseased plants, respectively (Table 21). The difference in the number of marketable tuberous roots between the healthy and diseased plants for Bukalasa 11 and Karemo was significant ($P<0.05$). Migyera was not affected by disease status and numbers were similar for healthy and diseased plants (Table 21). In Bukalasa 11, 38.3% and in Karemo, 30.8% of the diseased plants did not yield any tuberous roots. Healthy Karemo produced the highest number of tuberous roots, while diseased Bukalasa 11 produced the lowest. Healthy Bukalasa 11 produced the highest proportion [83.3%] of marketable tuberous roots, while healthy Karemo produced the lowest [68.8%] (Table 21).

Varieties differed significantly ($P<0.05$) in the number of tuberous roots produced; Bukalasa 11 produced significantly ($P<0.05$) fewer tuberous roots than the other two varieties (Table 21). The effect of interaction between disease status and variety on both types of tuberous roots was significant ($P<0.05$). The effect of disease status on non-marketable tuberous roots was not significant ($P>0.05$).

Table 21. Effect of disease status and variety on number of tuberous roots per plant

Type of roots	Variety	Disease status [z,y] Healthy	Diseased	Mean
Marketable	Migyera	4.6gh	5.1g	4.8a
	Bukalasa 11	3.0h	1.1i	2.0b
	Karemo	5.5g	1.7hi	3.6a
	Mean	4.5d	2.6e	
	Disease status $LSD_{0.05}$	1.4		
	Variety $LSD_{0.05}$	1.4		
	Interaction $LSD_{0.05}$	1.7		
	CV (%)	29.6		
Non-marketable	Migyera	1.5d	2.1d	1.8a
	Bukalasa 11	0.6e	0.5e	0.6b
	Karemo	2.5d	1.3d	1.9a
	Mean	1.6	1.3	
	Disease status $LSD_{0.05}$	NS		
	Variety $LSD_{0.05}$	0.6		
	Interaction $LSD_{0.05}$	1.7		
	CV (%)	34.3		

[z] Values followed by the same letter within each main factor and for each variable are not significantly different (NS) at $P \leq 0.05$.

[y] Interaction values followed by the same letter within each variable are not significantly different at $P \leq 0.05$.

(b) Weight of tuberous root

Disease status did not have a significant ($P>0.05$) effect on the weight of either marketable or non-marketable tuberous roots (Table 22). Marketable tuberous roots comprised more than 85% for all the varieties. Variety had a significant ($P<0.05$) effect on weight of tuberous roots. Weights for Karemo and Bukalasa 11 were not significantly different from each other, but were less and significantly different from those of Migyera. Yields of diseased and healthy Migyera were not statistically different, but were greater than those of the other two varieties (Table 22). Percentage yield losses of marketable tuberous roots were 62% for Bukalasa 11 and 73% for Karemo. There was a significant effect of interaction between disease status and variety on non-marketable tuberous root weight.

Table 22a. Effect of disease status and variety on tuberous root weight (kg/plant)

Type of roots	Variety	Disease status [z,y] Healthy	Diseased	Mean
Marketable	Migyera	2.3	2.3	2.3a
	Bukalasa 11	1.2	0.4	0.8b
	Karemo	1.8	0.5	1.2b
	Mean	1.8	1.1	
	Disease status $LSD_{0.05}$	NS		
	Variety $LSD_{0.05}$	0.7		
	Interaction $LSD_{0.05}$	NS		
	CV (%)	33.3		
Non-marketable	Migyera	0.1f	0.2e	0.2a
	Bukalasa 11	0.1f	0.0g	0.0c
	Karemo	0.2e	0.1f	0.1b
	Mean	0.1	0.1	
	Disease status $LSD_{0.05}$	NS		
	Variety $LSD_{0.05}$	0.1		
	Interaction $LSD_{0.05}$	0.1		
	CV (%)	35.5		

[z] Values followed by the same letter within each main factor and for each variable are not significantly different (NS) at $P \leq 0.05$.

[y] Interaction values followed by the same letter within each variable are not significantly different at $P \leq 0.05$.

Table 22b. Paired t-test comparison of weight kg/plant of marketable tuberous roots for different disease status in Bukalasa II and Karemo varieties

Variety	Disease Status	Tuberous roots	Disease Status	Tuberous roots	t-value	Significance [y]
Bukalasa 11	1	1.2	2	0.4	3.1	
Karemo	1	1.8	2	0.5	5,4	

[y] *, **, indicate significant at $P = 0.05$ and $P = 0.01$ respectively

(c) Harvest index

Harvest indices (HI) were significantly ($P<0.05$) different for disease status and variety (Table 23). Overall harvest indices for healthy and diseased plants were 0.4 and 0.3, respectively. Migyera had significantly ($P<0.05$) the highest harvest index of 0.5, whereas Bukalasa 11 and Karemo both had a harvest index of 0.3. Migyera had the highest HI regardless of disease status, whereas diseased Karemo and diseased Bukalasa 11 had the lowest. The HI in Bukalasa 11 and Karemo were significantly ($P<0.05$) different for the two disease states. There was a significant ($P<0.05$) disease status by variety interaction effect on HI (Table 23).

Table 23. Effect of disease status and variety on harvest indices per plant

	Disease status [z, y]		
Variety	Healthy	Diseased	Mean
Migyera	0.5a	0.5a	0.5a
Bukalasa 11	0.5a	0.2c	0.3b
Karemo	0.3b	0.2c	0.3b
Mean	0.4a	0.3b	
Disease status $LSD_{0.05}$	0.1		
Variety $LSD_{0.05}$	0.1		
Interaction $LSD_{0.05}$	0.1		
CV (%)	15.5		

[z] Values followed by the same letter within each main factor are not significantly different (NS) at $P \leq 0.05$.

[y] Interaction values followed by the same letter are not significantly different at $P \leq 0.05$.

4.3.4. Relationships between symptom severity index and either growth or yield variables

Linear regressions indicated significant ($P<0.05$), negative relationships between symptom severity index and height of plants for Migyera and Bukalasa at 3 MAP, but not for Karemo (Table 24). Apart from these results, all the other relationships between symptom severity index and growth variables (stem circumference and number of stems) were not significant ($P>0.05$).

There were significant ($P<0.05$), negative linear relationships between yield variables (biomass, number of tuberous roots, weight of tuberous roots, harvest index) and symptom severity index for varieties Bukalasa 11 and Karemo (Table 24). Plants yielding the lowest biomass were those with final disease symptom severity index of 4.0, which was most frequent for variety Bukalasa 11.

Table 24. Regression analysis values for relationships between symptom severity index and either height or yield variables of three cassava varieties

		Value [z]				
Variety	Variable	Intercept	Slope	r^2	F	Significance
Migyera	Height at 3 MAP	29.2	-7.4	0.83	18.9	***
	Biomass	2.0	0.3	0.10	0.5	NS
	Tuberous root number	4.9	1.1	0.15	0.7	NS
	Tuberous root weight	2.4	0.0	0.0	0.0	NS
	Harvest index	0.5	0.0	0.0	0.0	NS
Bukalasa 11	Height at 3 MAP	50.0	-6.8	0.69	8.9	*
	Biomass	1.5	-0.2	0.25	1.3	NS
	Tuberous root number	5.0	-0.9	0.92	50.5	**
	Tuberous root weight	1.7	-0.4	0.71	10.0	*
	Harvest index	0.6	-0.1	0.86	24.7	**
Karemo	Height at 3 MAP	45.3	-7.4	0.30	1.7	NS
	Biomass	5.5	-1.5	0.70	9.2	*
	Tuberous root number	11.3	-3.4	0.75	11.7	*
	Tuberous root weight	3.2	-1.1	0.85	23.2	**
	Harvest index	0.4	-0.1	0.92	50.8	**

[z]NS, *, **, *** indicate not significant at $P = 0.05$, significant at $P = 0.05$, $P = 0.01$ and $P = 0.001$, respectively; MAP indicates months after planting.

4.4. Experiment 4. Effects of Cultural Methods and Resistance in the Control of CMD

4.4.1. Disease (symptom) severity

Migyera, Karemo and Bukalasa 11 plants expressed CMD symptoms; however, the number of diseased plants was not significant in Migyera. Chi-square values for comparison of Karemo and Bukalasa 11 plants in different severity scores during progressive months of 2002 to 2003, resulted in mostly insignificant differences at Ugunja, except after 6 MAP when Bukalasa 11 had someplants in the 4.0 to 5.0 severity score category (Table 25a). The pattern was the same at Ugunja in 2003 to 2004, although differences were greatest at 8 MAP (Table 25b). At 4, 5 and 6 MAP, rogued plots had many plants in the 2.0 and 3.0 severity score categories of Karemo and Bukalasa 11, although differences were not significant (Table 25b).

At Karemo site in the 2002 to 2003 season, only variety Karemo was affected and hence no comparisons were made. In the 2003 to 2004 season, roguing was only done for Karemo, since Bukalasa 11 became infected after 5 MAP and had several plants in the 4 to 5 severity score category. There were significant differences starting at 6 MAP regardless of the treatment and this difference in severity scores was greatest at 8 MAP (Table 25c).

Figures 22 and 23 show disease symptom severity progression for the different management practices for each variety, site and season. In the 2002 to 2003 season, plants were initially healthy and severity score was 1.0 at 1 MAP. Some stems of Karemo sprouted diseased and were removed in all plots regardless of treatment (Figure 22). MM96/4466 did not develop any symptoms at either site in both seasons. Migyera developed symptoms that remained relatively constant at 2.0, or slightly increased until the end of the experiment. Symptoms in some of these plants disappeared with time. In 2002 to 2003, symptom severity score for Karemo and Bukalasa 11 was between 2.0 and 3.0 at both sites regardless of treatment (Figure 22).

In the 2003 to 2004 season, severity score was between 2.0 and 3.0 for Karemo at both sites and this score was highest in the control plots. For Bukalasa 11, the severity score was between 2.0 and 3.0 for all the treatments, except the control, which was slightly greater than 3.0, starting at the 6^{th} MAP at both sites. Symptom severity in the rogued plots in the 2003 to 2004 season decreased after the roguing exercise (4 MAP) and thereafter gradually increased over time (Figure 23).

Table 25a. Effect of management practice and variety on number of plants under different disease severity scores and on average severity scores at Ugunja during various times of the 2002 to 2003 season [z]

Time	Management		Disease severity score category				Avg.	
(MAP)	practice	Variety	1	2	3	4	score	χ^2
3	1	Karemo	4	58	8	0	2.1	3.5 NS
		Bukalasa 11	68	3	3	0	2.5	
	2	Karemo	6	59	0	0	2.0	-
		Bukalasa 11	72	2	0	0	2.5	
	3	Karemo	9	65	0	0	2.0	4.3*
		Bukalasa 11	60	13	2	0	2.1	
	4	Karemo	4	70	5	0	2.1	1.2 NS
		Bukalasa 11	73	2	0	0	2.0	
4	1	Karemo	0	25	19	0	2.4	0.0 NS
		Bukalasa 11	51	1	2	0	2.7	
	2	Karemo	2	11	34	0	2.8	4.5*
		Bukalasa 11	63	3	0	0	2.0	
	3	Karemo	6	18	23	0	2.6	0.0 NS
		Bukalasa 11	54	6	7	0	2.5	
	4	Karemo	1	9	43	0	2.8	7.04**
		Bukalasa 11	66	3	0	0	2.0	
5	1	Karemo	0	15	29	0	2.7	0.3 NS
		Bukalasa 11	54	0	3	0	3.0	
	2	Karemo	2	8	34	0	2.3	0.3 NS
		Bukalasa 11	65	2	3	0	2.9	
	3	Karemo	4	10	34	0	2.2	2.6 NS
		Bukalasa 11	41	10	12	0	2.8	
	4	Karemo	0	3	58	0	2.8	0.3 NS
		Bukalasa 11	59	3	3	0	2.5	
6	1	Karemo	1	7	38	0	2.8	0.1 NS
		Bukalasa 11	49	0	5	0	3.0	
	2	Karemo	0	2	45	0	3.0	0.6 NS
		Bukalasa 11	57	0	5	0	3.0	
	3	Karemo	2	6	37	0	2.9	5.0 NS
		Bukalasa 11	41	0	17	1	3.0	
	4	Karemo	0	1	54	0	3.0	3.9*
		Bukalasa 11	51	2	6	0	2.8	
7	1	Karemo	1	7	37	0	2.8	5.8*
		Bukalasa 11	44	0	10	1	3.0	
	2	Karemo	0	5	51	0	3.0	0.5 NS
		Bukalasa 11	58	0	5	1	3.0	
	3	Karemo	3	8	31	0	2.9	9.9**
		Bukalasa 11	41	0	18	3	3.0	
	4	Karemo	0	5	51	0	3.0	9.3**
		Bukalasa 11	52	2	5	1	2.8	
8	1	Karemo	1	4	30	0	2.9	3.6 NS
		Bukalasa 11	43	1	10	1	3.0	
	2	Karemo	0	2	42	0	3.0	2.6 NS
		Bukalasa 11	57	2	4	0	2.7	
	3	Karemo	2	2	35	0	2.9	19.3***
		Bukalasa 11	41	0	12	9	3.4	
	4	Karemo	0	5	50	0	2.9	20.8***
		Bukalasa 11	46	2	1	1	2.8	

[z] MAP = months after planting; 1= roguing, 2= choice of planting material, 3= roguing+choice of planting material, 4= control; average severity score does not include baseline value "1"; χ^2 = chi-square value; NS, *, **, ***, indicate not significant, significant at $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

Table 25b. Effect of management practice and variety on number of plants under different disease severity scores and on average severity scores at Ugunja during various times of the 2003 to 2004 season [z]

Time	Management		Disease severity score category				Avg.	
(MAP)	practice	Variety	1	2	3	4	score	χ^2
3	1	Karemo	13	56	13	0	2.2	1.3 NS
		Bukalasa 11	40	27	12	0	2.3	
	2	Karemo	30	50	4	0	2.1	2.4 NS
		Bukalasa 11	54	21	6	0	2.2	
	3	Karemo	29	46	6	0	2.1	3.8*
		Bukalasa 11	50	16	8	0	2.3	
	4	Karemo	14	53	16	0	2.2	1.6 NS
		Bukalasa 11	41	24	14	0	2.4	
4	1	Karemo	13	2	0	0	2.0	-
		Bukalasa 11	35	1	0	0	2.0	
	2	Karemo	20	49	9	0	2.2	6.8**
		Bukalasa 11	50	15	12	0	2.4	
	3	Karemo	28	3	0	0	2.0	-
		Bukalasa 11	44	4	0	0	2.0	
	4	Karemo	13	52	20	0	2.3	1.1 NS
		Bukalasa 11	35	23	15	1	2.4	
5	1	Karemo	9	6	0	0	2.0	0.8 NS
		Bukalasa 11	20	12	5	0	2.3	
	2	Karemo	15	49	14	0	2.2	8.1*
		Bukalasa 11	41	18	16	1	2.5	
	3	Karemo	11	18	1	0	2.1	0.1NS
		Bukalasa 11	36	11	1	0	2.1	
	4	Karemo	11	46	26	1	2.4	12.7*
		Bukalasa 11	24	18	28	6	2.8	
6	1	Karemo	2	9	5	0	2.4	0.1
		Bukalasa 11	15	16	5	0	2.2	
	2	Karemo	5	37	35	0	2.5	7.7*
		Bukalasa 11	33	4	30	7	3.1	
	3	Karemo	2	19	9	0	2.3	5.6 NS
		Bukalasa 11	24	8	13	1	2.7	
	4	Karemo	3	33	43	4	2.6	30.0***
		Bukalasa 11	15	10	25	25	3.3	
7	1	Karemo	2	9	8	0	2.5	0.0 NS
		Bukalasa 11	14	11	11	0	2.5	
	2	Karemo	5	39	33	0	2.5	28.3***
		Bukalasa 11	33	5	28	8	3.1	
	3	Karemo	2	16	10	0	2.4	3.7 NS
		Bukalasa 11	25	8	13	1	2.7	
	4	Karemo	2	35	42	4	2.6	30.9***
		Bukalasa 11	15	10	25	25	3.3	
8	1	Karemo	1	7	8	0	2.5	0.9 NS
		Bukalasa 11	13	6	17	0	2.7	
	2	Karemo	1	67	8	0	2.1	81.4***
		Bukalasa 11	25	4	32	13	3.2	
	3	Karemo	1	24	5	0	2.2	24.4***
		Bukalasa 11	18	5	20	3	2.9	
	4	Karemo	0	58	24	0	2.3	69.4***
		Bukalasa 11	9	4	37	21	3.3	

[z] MAP = months after planting; 1= roguing, 2= choice of planting material, 3= roguing+choice of planting material, 4= control; average severity score does not include baseline value "1"; χ^2 = chi-square value; NS, *, **, ***, indicate not significant, significant at $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

Table 25c. Effect of management practice and variety on number of plants under different severity scores and on average severity scores at Karemo during various times of the 2003 to 2004 season [z]

Time	Management		Disease severity score category				Avg.	
(MAP)	practice	Variety	1	2	3	4	score	χ^2
6	1	Karemo	4	8	7	0	2.5	4.9 NS
		Bukalasa 11	66	5	6	4	2.9	
	2	Karemo	17	49	10	0	2.2	23.8***
		Bukalasa 11	62	5	10	3	2.9	
	3	Karemo	13	26	2	0	2.1	16.4***
		Bukalasa 11	66	5	6	3	2.9	
	4	Karemo	2	30	45	3	2.7	17.9***
		Bukalasa 11	59	5	13	9	3.1	
7	1	Karemo	3	12	5	0	2.3	7.6*
		Bukalasa 11	68	4	5	4	3.0	
	2	Karemo	14	49	8	0	2.1	18.3***
		Bukalasa 11	62	7	7	3	2.8	
	3	Karemo	4	52	23	1	2.3	14.3***
		Bukalasa 11	59	5	13	9	3.1	
	4	Karemo	0	14	4	0	2.2	31.8***
		Bukalasa 11	49	11	12	6	2.8	
8	1	Karemo	0	14	4	0	2.2	8.3*
		Bukalasa 11	49	11	12	6	2.8	
	2	Karemo	0	72	5	0	2.1	46.3***
		Bukalasa 11	51	9	17	3	2.8	
	3	Karemo	1	37	4	0	2.1	46.3***
		Bukalasa 11	47	13	17	4	2.7	
	4	Karemo	0	45	34	2	2.5	32.6***
		Bukalasa 11	48	6	17	4	2.9	

[z] MAP = months after planting; 1= roguing, 2= choice of planting material, 3= roguing+choice of planting material, 4= control; average severity score does not include baseline value "1"; χ^2 = chi-square value; NS, *, **, ***, indicate not significant, significant at $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

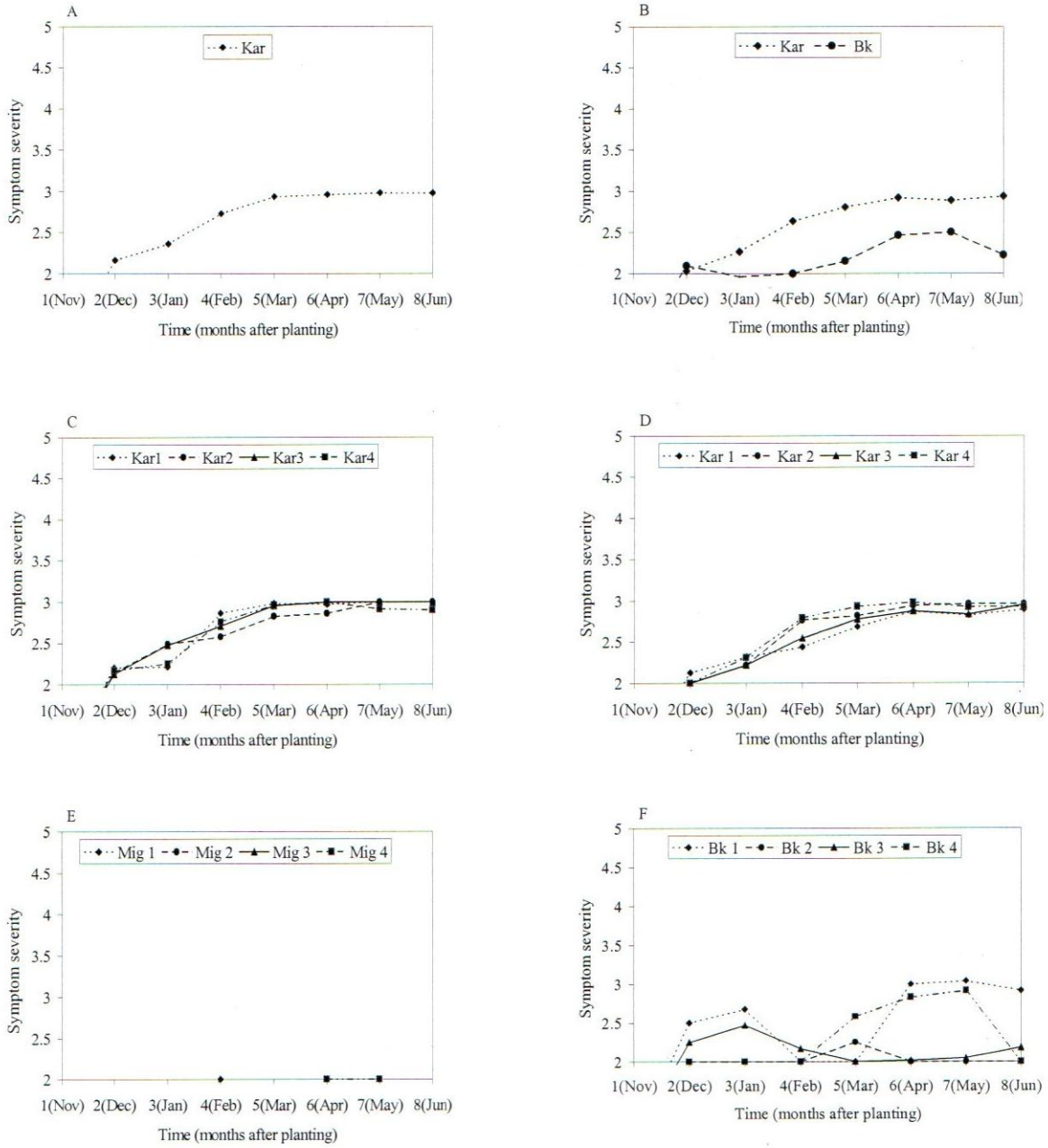


Figure 22. Cassava mosaic disease symptom severity index for Karemo division in Nov 2002 to June 2003 (A), Ugunja division in Nov 2002 to June 2003 (B), Karemo variety in Karemo division and Nov 2002 to June 2003 (C), Karemo variety in Ugunja division and Nov 2002 to June 2003 (D), Migyera variety in Ugunja division and Nov 2002 to June 2003 (E), Bukalasa 11 variety in Ugunja division and Nov 2002 to June 2003 (F). Kar = Karemo, Mig = Migyera, Bk = Bukalasa 11, 1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

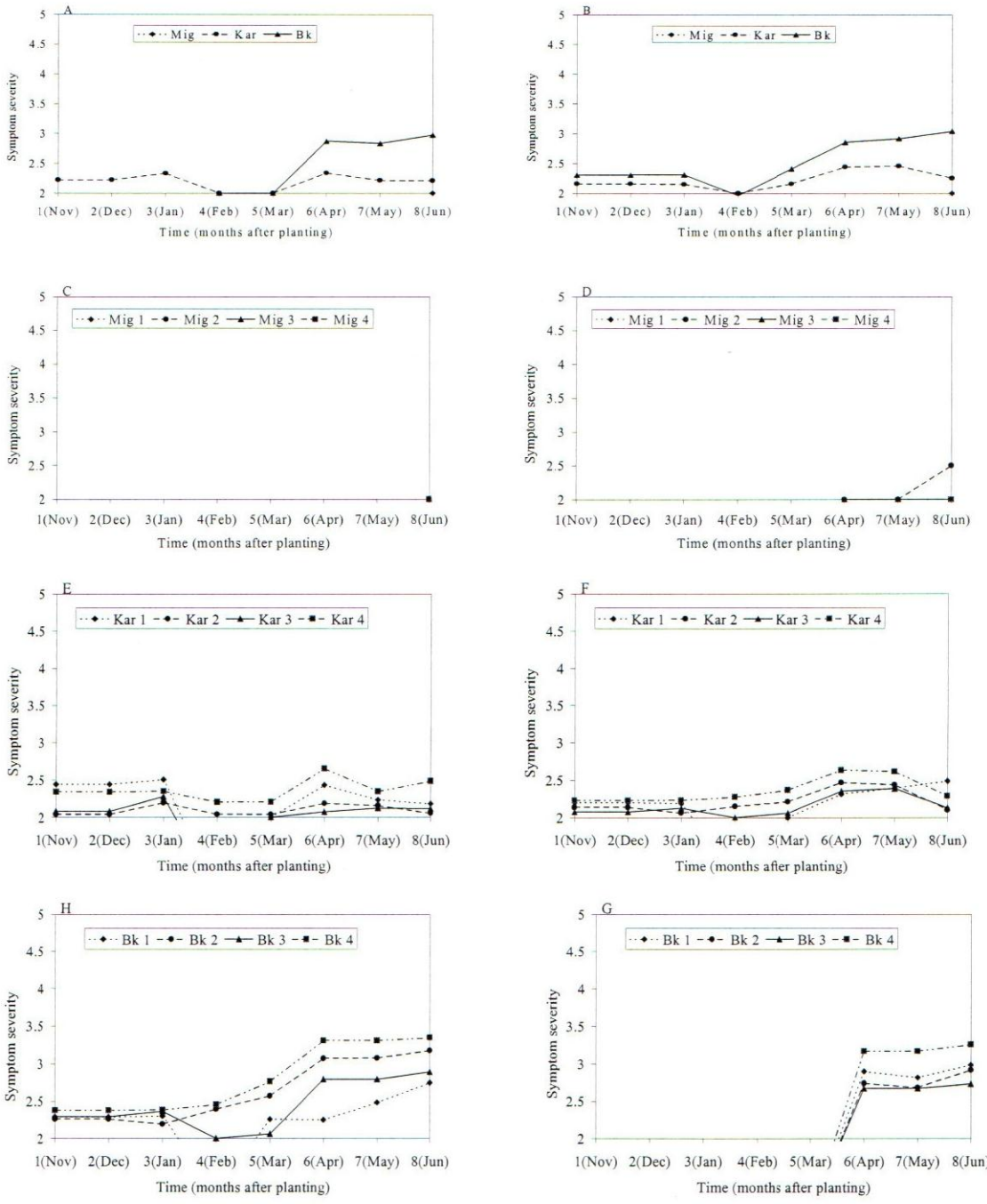


Figure 23. Cassava mosaic disease symptom severity index for Karemo division in Nov 2003 to June 2004 (A), Ugunja division in Nov 2003 to June 2004 (B), Migyera variety in Karemo division and Nov 2003 to June 2004 (C), Migyera variety in Ugunja division and Nov 2003 to June 2004 (D), Karemo variety in Karemo division and Nov 2003 to June 2004 (E), Karemo variety in Ugunja division and Nov 2003 to June 2004 (F), Bukalasa 11 variety in Karemo division and Nov 2003 to June 2004 (G), Bukalasa 11 variety in Ugunja division and Nov 2003 to June 2004 (H). Kar = Karemo, Mig = Migyera, Bk = Bukalasa 11, 1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

4.4.2. Disease incidence

At the Karemo, only variety Karemo was affected by CMD in the 2002 to 2003 season; in the 2003 to 2004 season, Migyera, Karemo and Bukalasa 11 were affected by CMD, although the final incidence in Migyera was less than 10% in each season (Table 26). At the Ugunja site, Bukalasa 11 and Karemo were affected in the 2002 to 2003 season, whereas Migyera was affected in the 2003 to 2004 season. The final incidence was generally higher at Ugunja than at Karemo, and in the 2003 to 2004 season than in the 2002 to 2003 season at both sites (Table 26).

First infections in variety Karemo were recorded at two months after planting (MAP) at both sites in the 2002 to 2003 season. In the 2003 to 2004 season, Karemo started out diseased in all treatments at both sites. Bukalasa 11 started out diseased in the 2003 to 2004 season for the no choice of planting material treatments at Ugunja; at Karemo, first infections were recorded at 5 MAP. In Migyera, first infections were observed at 4 MAP and 3 MAP in the 2002 to 2003 season and the 2003 to 2004 season, respectively at Ugunja, and at 8 MAP in the 2003 to 2004 season at Karemo (Figures 24 and 25).

The disease spread was fastest in variety Karemo at both sites, while MM96/4466 was not affected by CMD at either of the two sites. The incidence in varieties that were affected by CMD increased progressively with time. The cumulative percentage of diseased plants in Karemo and Bukalasa 11 decreased in the rogued treatments immediately after the roguing exercise (4 MAP) of the 2003 to 2004 season at both sites (Figures 24 and 25).

Table 26. Final disease incidence (%) for varieties and management practices at Karemo and Ugunja divisions during the 2002 to 2003 and 2003 to 2004 seasons

Site	Year (season)	Variety	Management practice [z]			
			1	2	3	4
Karemo	November 2002 to June 2003	MM96/4466	0	0	0	0
		Migyera	0	0	0	0
		Karemo	100	100	100	100
		Bukalasa 11	0	0	0	0
	November 2003 to June 2004	MM96/4466	0	0	0	0
		Migyera	6.2	8.2	1.3	3.6
		Karemo	100	100	97.2	100
		Bukalasa 11	37.6	35.9	41.0	45.0
Ugunja	November 2002 to June 2003	MM96/4466	0	0	0	0
		Migyera	0	0	0	0
		Karemo	98.1	100	93.8	100
		Bukalasa 11	65.1	67.1	60.4	86.6
	November 2003 to June 2004	MM96/4466	0	0	0	0
		Migyera	6.0	19.3	6.7	9.8
		Karemo	91.7	98.4	95.8	100
		Bukalasa 11	22.0	9.4	30.3	7.4

[z] 1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

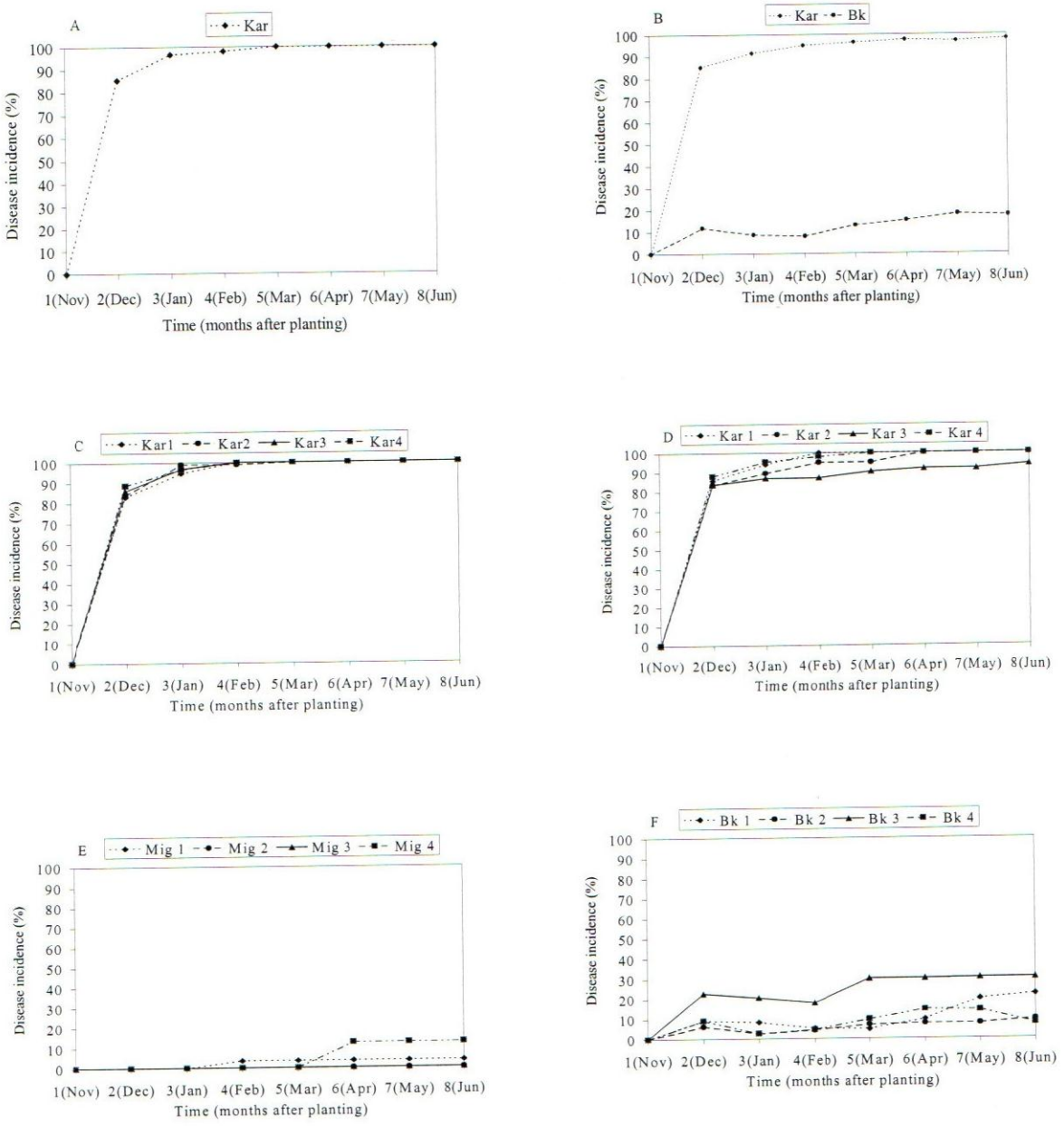


Figure 24. Cassava mosaic disease incidence for Karemo division in Nov 2002 to June 2003 (A), Ugunja division in Nov 2002 to June 2003 (B), Karemo variety in Karemo division and Nov 2002 to June 2003 (C), Karemo variety in Ugunja division and Nov 2002 to June 2003 (D), Migyera variety Ugunja division and Nov 2002 to June 2003 (E), and Bukalasa 11 variety in Ugunja division and Nov 2002 to June 2003 (F). Kar = Karemo, Mig = Migyera, Bk = Bukalasa 11, 1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

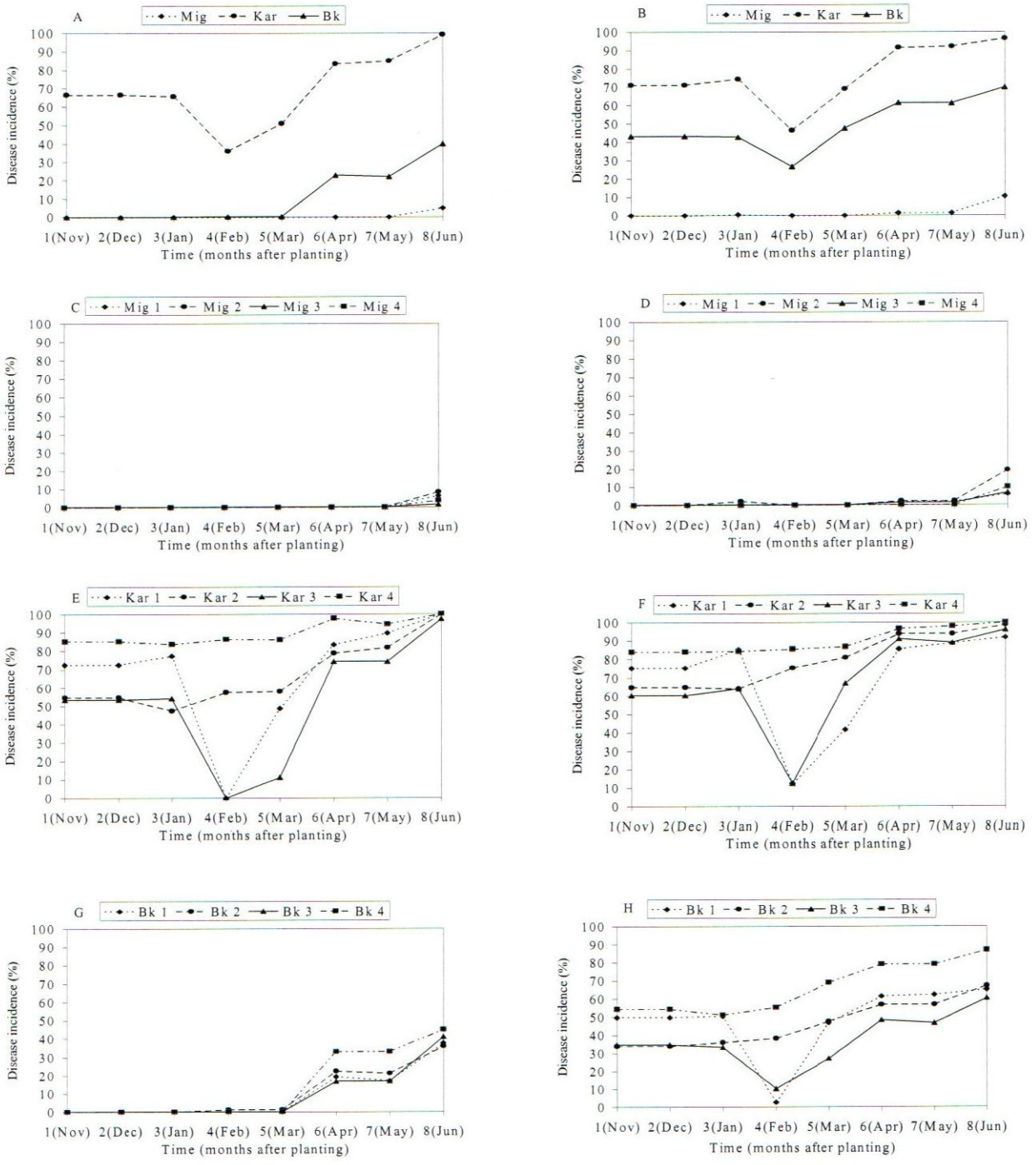


Figure 25. Cassava mosaic disease incidence for Karemo division in Nov 2003 to June 2004 (A), Ugunja division in Nov 2003 to June 2004 (B), Migyera variety in Karemo division and Nov 2003 to June 2004 (C), Migyera variety in Ugunja division and Nov 2003 to June 2004 (D), Karemo variety in Karemo division and Nov 2003 to June 2004 (E), Karemo variety in Ugunja division and Nov 2003 to June 2004 (F), Bukalasa 11 variety in Karemo division and Nov 2003 to June 2004 (G), Bukalasa 11 variety in Ugunja division and Nov 2003 to June 2004 (H). Kar = Karemo, Mig = Migyera, Bk = Bukalasa 11, 1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

4.4.3. Number of adult whiteflies

Number of adult *B. tabaci* was generally moderate and averaged less than 40 per plant throughout the monitoring period at each site (Figure 26). Adult whiteflies were generally greatest between 4 and 6 MAP for each variety in each year, after which the population declined. Abundance was greatest in MM96/4466 and least in Karemo (Figure 26). There was a significant effect of variety on number of adult whiteflies (Tables 27a – 27d). Small and non-significant differences in number of adult whiteflies resulted for management practices of the different varieties in both sites during each season. The effect of variety by management practice interaction on number of adult whiteflies was not significant (Tables 27a – 27d).

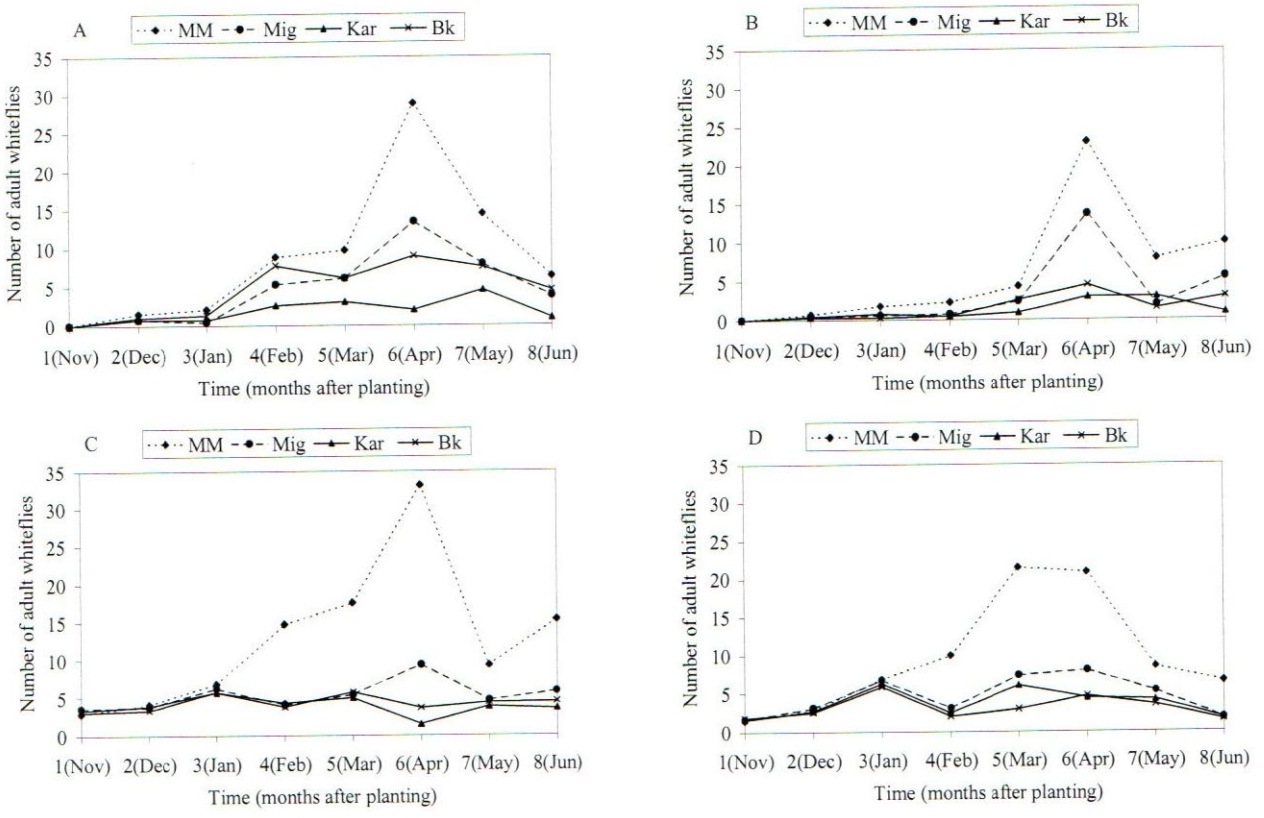


Figure 26. Abundance of whiteflies for Karemo in November 2002 to June 2003 (A), Ugunja in November 2002 to June 2003 (B), Karemo in November 2003 to June 2004 (C), Ugunja in November 2003 to June 2004 (D). MM = MM96/4466, Mig = Migyera, Kar = Karemo, Bk = Bukalasa 11.

Table 27a. Effect of variety and management practice on number of adult whiteflies at Karemo during various times of the November 2002 to June 2003 season

Time after planting	Variety	Management practice [z,y] 1	2	3	4	Mean
December	MM96/4466	1.6	0.9	2.4	1.2	1.5
	Migyera	0.3	0.8	1.0	0.9	1.7
	Karemo	0.3	0.4	1.2	1.3	0.8
	Bukalasa 11	0.4	1.1	1.4	1.1	1.0
	Mean	0.7	0.8	1.5	1.1	
January	MM96/4466	3.0	1.9	1.8	1.7	2.1a
	Migyera	0.4	0.4	0.2	0.7	0.4c
	Karemo	0.5	0.9	1.0	0.5	0.7c
	Bukalasa 11	1.0	1.8	1.1	1.3	1.3b
	Mean	1.1	1.3	1.4	1.1	
February	MM96/4466	9.5	6.2	8.5	11.2	8.8a
	Migyera	6.8	3.9	4.6	6.1	5.3bc
	Karemo	1.5	3.7	2.3	2.9	2.6c
	Bukalasa 11	11.0	6.0	5.9	8.0	7.7ab
	Mean	7.2	5.0	5.3	7.1	
March	MM96/4466	10.0	9.1	7.5	12.4	9.7a
	Migyera	8.3	4.5	6.8	5.0	6.1b
	Karemo	3.0	3.2	3.2	2.9	3.1c
	Bukalasa 11	5.9	8.6	6.8	2.6	5.9b
	Mean	6.8	6.4	6.1	5.7	
April	MM96/4466	22.7	34.1	25.9	32.8	28.8a
	Migyera	14.6	12.3	18.6	8.3	13.4b
	Karemo	2.8	2.3	0.9	2.2	2.0c
	Bukalasa 11	8.2	6.1	8.8	7.9	7.7b
	Mean	12.1	13.7	13.6	12.8	
May	MM96/4466	10.9	14.5	16.4	15.7	14.4a
	Migyera	6.7	11.7	5.1	8.1	7.9b
	Karemo	6.6	2.5	7.9	1.3	4.6b
	Bukalasa 11	5.6	4.5	8.6	9.7	7.1b
	Mean	7.5	8.3	9.5	8.7	8.5
June	MM96/4466	4.0	8.1	6.9	6.2	6.3a
	Migyera	3.8	2.9	2.8	5.7	3.8a
	Karemo	2.0	0.3	1.4	0.0	0.9b
	Bukalasa 11	3.2	6.2	3.2	5.1	4.4a
	Mean	3.3	4.4	3.6	4.3	

[z] 1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y] Values not followed by a letter or followed by the same letter within each factor and time are not significantly different at $P \leq 0.05$.

Table 27b. Effect of variety and management practice on number of adult whiteflies at Ugunja during various times of the November 2002 to June 2003 season

Time after planting	Variety	Management practice [z,y] 1	2	3	4	Mean
December	MM96/4466	0.8	1.1	0.4	0.6	0.7a
	Migyera	0.3	0.7	0.3	0.2	0.4b
	Karemo	0.6	0.4	0.5	0.4	0.4b
	Bukalasa 11	0.2	0.3	0.2	0.3	0.3b
	Mean	0.5	0.6	0.4	0.4	
January	MM96/4466	2.5	1.6	1.4	1.6	1.8a
	Migyera	0.8	0.3	0.5	0.7	0.6b
	Karemo	1.1	0.9	0.5	0.6	0.8b
	Bukalasa 11	0.1	0.3	0.2	0.1	0.2c
	Mean	1.1	0.8	0.7	0.8	
February	MM96/4466	2.6	1.8	1.8	2.9	2.3a
	Migyera	0.7	0.5	1.0	0.7	0.7b
	Karemo	0.5	0.6	0.3	0.5	0.5b
	Bukalasa 11	0.3	0.3	0.3	0.6	0.4b
	Mean	1.0	0.8	0.8	1.2	
March	MM96/4466	4.5	3.1	5.7	4.0	4.3a
	Migyera	2.6	2.3	3.1	1.6	2.4b
	Karemo	1.1	1.1	0.8	0.7	0.9b
	Bukalasa 11	0.9	3.5	3.5	1.7	2.4b
	Mean	2.3	2.5	3.3	2.0	
April	MM96/4466	15.1	18.3	20.6	38.2	23.0a
	Migyera	14.9	12.0	17.2	10.5	13.6b
	Karemo	3.0	4.3	2.5	2.1	3.0c
	Bukalasa 11	3.1	2.7	5.9	1.7	3.3c
	Mean	9.0	9.3	11.6	13.1	
May	MM96/4466	9.0	6.8	6.9	9.1	7.9a
	Migyera	2.1	1.6	1.4	2.6	1.9bc
	Karemo	3.9	2.0	3.0	3.1	3.0b
	Bukalasa 11	0.8	0.9	1.9	0.8	1.1c
	Mean	4.0	2.8	3.3	3.9	
June	MM96/4466	8.8	8.3	6.9	16.1	10.0a
	Migyera	7.5	6.8	2.9	4.8	5.5b
	Karemo	0.4	0.8	1.1	1.3	0.9c
	Bukalasa 11	7.5	1.4	0.6	0.7	2.6bc
	Mean	6.1	4.3	2.9	5.7	

[z] 1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y] Values not followed by a letter or followed by the same letter within each factor and time are not significantly different at $P \leq 0.05$.

Table 27c. Effect of variety and management practice on number of adult whiteflies at Karemo during various times of the November 2003 to June 2004 season

Time after planting	Variety	Management practice [z,y] 1	2	3	4	Mean
December	MM96/4466	4.2	4.4	4.0	3.8	4.1
	Migyera	3.1	3.5	4.4	4.1	3.7
	Karemo	3.8	3.9	4.0	3.8	3.8
	Bukalasa 11	2.6	3.2	4.2	3.2	3.3
	Mean	3.4	3.7	4.2	3.7	
January	MM96/4466	7.7	6.7	6.3	6.5	6.8
	Migyera	6.7	6.2	5.9	5.9	6.2
	Karemo	7.5	4.3	4.5	6.2	5.6
	Bukalasa 11	4.9	6.7	5.2	5.5	6.1
	Mean	6.7	6.0	5.5	6.0	
February	MM96/4466	16.7	18.6	12.8	10.8	14.7a
	Migyera	4.3	5.0	3.4	3.4	4.0b
	Karemo	5.7	4.2	4.6	2.9	4.3b
	Bukalasa 11	5.5	1.4	1.8	3.7	3.1b
	Mean	8.1	7.3	5.6	5.2	
March	MM96/4466	22.5	19.5	12.1	16.1	17.5a
	Migyera	6.1	5.4	5.6	4.3	5.4b
	Karemo	6.5	4.4	6.3	2.6	4.9b
	Bukalasa 11	7.7	2.4	4.0	5.6	4.9b
	Mean	10.7	7.9	7.0	7.2	
April	MM96/4466	43.2	35.8	27.2	25.7	33.0a
	Migyera	6.6	7.9	12.2	10.5	9.3b
	Karemo	2.0	1.2	1.4	1.0	1.4b
	Bukalasa 11	4.6	3.5	3.8	4.0	4.0b
	Mean	14.1	12.1	11.2	10.3	
May	MM96/4466	10.8	10.5	7.6	7.9	9.2a
	Migyera	4.8	4.7	4.6	4.3	4.6b
	Karemo	5.5	4.0	4.5	1.0	3.8b
	Bukalasa 11	4.6	3.5	3.8	4.0	4.0b
	Mean	6.4	5.7	5.1	4.3	
June	MM96/4466	18.6	16.9	12.4	12.5	15.1a
	Migyera	5.4	5.6	6.3	5.6	5.7b
	Karemo	5.1	3.6	4.2	1.0	3.5b
	Bukalasa 11	4.4	3.1	3.4	3.9	3.7b
	Mean	8.4	7.3	6.6	5.7	

[z] 1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y] Values not followed by a letter or followed by the same letter within each factor and time are not significantly different at $P \leq 0.05$.

Table 27d. Effect of variety and management practice on number of adult whiteflies at Ugunja during various times of the November 2003 to June 2004 season

Time after planting	Variety	Management practice [z,y] 1	2	3	4	Mean
December	MM96/4466	2.7	2.4	3.2	2.8	2.8
	Migyera	3.1	3.4	2.8	2.9	3.0
	Karemo	2.7	2.4	2.9	2.6	2.6
	Bukalasa 11	2.5	2.2	3.0	2.2	2.5
	Mean	2.7	2.6	3.0	2.6	
January	MM96/4466	5.5	7.3	6.8	7.6	6.8
	Migyera	7.9	7.2	6.5	5.3	6.7
	Karemo	6.6	6.4	5.7	6.3	6.2
	Bukalasa 11	6.6	7.1	5.5	3.8	5.8
	Mean	6.6	7.0	6.1	5.7	
February	MM96/4466	9.1	11.5	9.2	9.8	9.9a
	Migyera	3.4	1.9	3.4	3.3	3.0b
	Karemo	2.6	3.4	1.5	2.0	2.4b
	Bukalasa 11	1.5	1.7	1.4	1.3	1.5b
	Mean	4.2	4.6	3.9	4.1	
March	MM96/4466	26.0	27.0	15.7	17.2	21.5a
	Migyera	6.3	7.8	6.4	8.6	7.3b
	Karemo	5.3	7.5	5.6	5.2	6.0b
	Bukalasa 11	1.4	2.4	1.4	1.7	1.7c
	Mean	9.7	11.2	7.3	8.2	
April	MM96/4466	22.5	29.5	14.9	16.5	20.8a
	Migyera	8.5	8.5	7.5	7.2	7.9b
	Karemo	3.6	5.2	2.3	3.2	4.3c
	Bukalasa 11	3.0	4.2	3.7	3.4	3.6c
	Mean	9.4	11.8	7.1	7.6	
May	MM96/4466	8.7	8.6	8.7	7.5	8.4a
	Migyera	5.6	4.3	5.8	4.9	5.2b
	Karemo	4.6	4.8	4.6	2.3	4.1b
	Bukalasa 11	4.8	3.1	2.2	2.6	3.1b
	Mean	5.9	5.2	5.3	4.3	
June	MM96/4466	6.1	8.5	5.5	5.8	6.4a
	Migyera	1.5	2.2	1.6	1.5	1.7b
	Karemo	2.3	1.9	1.4	1.3	1.7b
	Bukalasa 11	1.2	1.2	1.2	1.2	1.2b
	Mean	2.8	3.5	2.4	2.5	

[z] 1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y] Values not followed by a letter or followed by the same letter within each factor and time are not significantly different at $P \leq 0.05$.

4.4.4. Cassava biomass and tuberous root yields

(a) Biomass

Plant biomass was measured only in the second (2003 to 2004) season (Table 28). There were variations in biomass yields for the different varieties. Karemo resulted in the highest average biomass of 38.8 and 23.0 kg/plot at Karemo and Ugunja, respectively. Migyera and Bukalasa 11 yielded low biomass of 16.6 and 19.1 kg/plot, respectively at Karemo, whereas Bukalasa 11 yielded the lowest biomass of 8.3 kg/plot at Ugunja (Table 28).

Biomass production was significantly ($P<0.05$) different for the four varieties at both sites and for the management practices at Ugunja. There were small, but non-significant ($P>0.05$) differences in biomass production among management practices of the different varieties at Karemo. The effect of variety by management practice interaction on biomass production was not significant ($P>0.05$) at Karemo, but it was significant at Ugunja (Table 28).

Table 28. Effect of variety and management practice on biomass production (kg/plot) in Karemo and Ugunja during the 2003 to 2004 season

		Management practice [z,y]				
Site	Variety	1	2	3	4	Mean
Karemo	MM96/4466	38.5	38.9	32.9	27	34.3a
	Migyera	17.3	18.4	17.9	12.9	16.6b
	Karemo	15.2	57.5	38.6	43.8	38.8a
	Bukalasa 11	16.9	22	22.9	14.5	19.1b
	Mean	22	34.2	28.1	24.5	
	Variety $LSD_{0.05}$	10.2				
	Management $LSD_{0.05}$	NS				
	Interaction $LSD_{0.05}$	NS				
	CV (%)	13.7				
Ugunja	MM96/4466	19.9jk	15.6kl	15.3kl	16.2kl	16.7b
	Migyera	15.3kl	28.0ij	13.0kl	19.7jk	19.0a
	Karemo	7.8kl	40.5h	10.2kl	33.6hi	23.0a
	Bukalasa 11	6.3l	10.3k	6.8l	9.6kl	8.3c
	Mean	12.3f	23.6e	11.9f	19.7e	
	Variety $LSD_{0.05}$	6.2				
	Management $LSD_{0.05}$	6.2				
	Interaction $LSD_{0.05}$	12.4				
	CV (%)	16.6				

[z] 1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y] Values not followed by a letter or followed by the same letter within each factor and site are not significantly different at $P\leq 0.05$.

(b) Number of tuberous roots

The number of tuberous roots was generally higher in the 2002 to 2003 season than in the 2003 to 2004 season (Tables 29a and 29b). There was a significant ($P<0.05$) effect of variety on the number of tuberous roots at both sites in each season (Tables 29a and 29b). In the 2002 to 2003 season, the highest number of tuberous roots at both sites resulted in MM96/4466, whereas in the 2003 to 2004 season, they resulted in MM96/4466 at Karemo, and MM96/4466 and Migyera at Ugunja. Karemo and Bukalasa 11 generally yielded the lowest number of tuberous roots at both sites in each season.

Management practices had a significant ($P<0.05$) effect on the number of tuberous roots at Karemo in the 2002 to 2003 season, and at Ugunja in 2003 to 2004. The effect of variety by management practice interaction was not significant ($P>0.05$) at both sites and in both seasons (Tables 29a and 29b). In the CMD-susceptible variety Karemo, specific analysis showed management practice having a significant ($P<0.05$) effect on the number of tuberous roots at both sites in the 2003 to 2004 season (Table 29b). Choice of clean planting material practice resulted in the highest number of tuberous roots in 2003 to 2004 season (Table 29b). A similar analysis for Bukalasa 11 showed management practice having no significant ($P>0.05$) effect at any site in both seasons (Tables 29a and 29b).

Paired t-test comparisons showed either rouging or choice of planting material to be different from the control in Karemo variety in the 2003 to 2004 season (Table 29c). In rouging or choice of planting material treatments, differences were either not significant or the control was greater (Table 29c). When compared to the resistant varieties, Karemo choice of planting material was different and had a greater number of tuberous roots than both MM96/4466 and Migyera. When the control in Karemo was compared to the resistant varieties, there was no significant difference in number of tuberous roots per plot (Table 29c)

Table 29a. Effect of variety and management practice on number of tuberous roots per plot at Karemo and Ugunja during the 2002 to 2003 season

Site	Variety	Management practice [z,y] 1	2	3	4	Mean
Karemo	MM96/4466	131.2	107.2	115.2	105.8	114.9a
	Migyera	85.8	84.5	72.0	63.0	76.3b
	Karemo	86.2	71.5	44.2	51.5	63.4b
	Bukalasa 11	78.5	85.8	77.0	44.2	71.4b
	Mean	95.4d	87.2d	77.1d	66.1e	
	Variety $LSD_{0.05}$	20.8				
	Management $LSD_{0.05}$	20.8				
	Interaction $LSD_{0.05}$	NS				
	CV (%)	18.2				
Ugunja	MM96/4466	141.2	116.7	133.8	130.3	130.5a
	Migyera	103.8	104.7	87.0	78.8	93.6b
	Karemo	83.8	93.2	52.3	77.0	76.5c
	Bukalasa 11	71.8	76.0	78.1	70.3	74.0c
	Mean	100.1	97.6	87.8	89.1	
	Variety $LSD_{0.05}$	14.2				
	Management $LSD_{0.05}$	NS				
	Interaction $LSD_{0.05}$	NS				
	CV (%)	16.7				

[z]1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y]Values not followed by a letter or followed by the same letter within each factor and site are not significantly different at $P \leq 0.05$.

Table 29b. Effect of variety and management practice on number of tuberous roots per plot at Karemo and Ugunja during the 2003 to 2004 season

Site	Variety	Management practice [z,y] 1	2	3	4	Mean
Karemo	MM96/4466	115.0	114.3	90.6	88.0	102.0a
	Migyera	60.8	59.6	65.8	53.3	59.8bc
	Karemo	38.5f	110.4e	62.2f	74.8ef	73.3b
	Bukalasa 11	48.0	49.0	52.0	37.5	46.6c
	Mean	64.0	83.3	69.3	65.5	
	Variety $LSD_{0.05}$	20.6				
	Management $LSD_{0.05}$	NS				
	Interaction $LSD_{0.05}$	NS				
	CV (%)	17.0				
Ugunja	MM96/4466	82.8	76.8	68.2	51.8	69.9a
	Migyera	68.8	86	69.5	74.7	76.5a
	Karemo	21.2i	99.2h	24.0i	56.2i	50.2b
	Bukalasa 11	21.5	43.0	23.4	41.3	32.3c
	Mean	48.6f	76.3e	46.3f	56.7f	
	Variety $LSD_{0.05}$	18.6				
	Management $LSD_{0.05}$	18.6				
	Interaction $LSD_{0.05}$	37.1				
	CV (%)	18.0				

[z]1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y]Values not followed by a letter or followed by the same letter within each factor and site are not significantly different at $P \leq 0.05$.

Table 29c. Paired t-test comparison of number of tuberous roots per plot for different varieties and management practice at Karemo and Ugunja during the 2003 to 2004 season

Variety	Management practice [z]	Tuberous roots	Management practice	Tuberous roots	t-value	Significance [y]
Karemo	1	29.9	4	65.5	-4.8	***
Karemo	2	104.9	4	65.5	14.5	***
Karemo	3	43.1	4	65.5	-1.95	NS

Management practice	Variety	Tuberous roots	Variety	Tuberous roots	t-value	Significance
2	Karemo	104.9	MM96/4466	79.4	2.4	*
2	Karemo	104.9	Migyera	67.2	2.4	*
4	Karemo	65.5	MM96/4466	69.8	0.3	NS
4	Karemo	65.5	Migyera	64.0	0.1	NS

[z]1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y]NS, *, **, ***, indicate not significant, significant at $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

(c) Weight of tuberous roots

The average total weight of tuberous roots ranged from 3.8 to 69.2 kg/plot; the weight was generally higher in the 2002 to 2003 season (Tables 30a and 30b). Variety had a significant ($P<0.05$) effect on the weight of marketable tuberous roots at each site in both seasons (Tables 30a and 30b). The highest weight of marketable tuberous roots was for MM96/4466, whereas the lowest was for Karemo. The effect of management practice, as well as variety by management practice interaction, on weight of tuberous roots was only significant ($P<0.05$) at Ugunja in the 2003 to 2004 season (Tables 30a and 30b).

In the CMD-susceptible variety Karemo, specific analysis showed management practice having a significant ($P<0.05$) effect on the weight of tuberous roots at both sites and in both seasons, except at Karemo in 2002 to 2003 (Tables 30a and 30b). Choice of clean planting material practice resulted in the highest weight of tuberous roots per plot (Tables 30a and 30b).

A similar analysis for Bukalasa 11 showed management practice having no significant ($P<0.05$) effect at any site in both seasons (Tables 30a and 30b).

Paired t-test comparisons showed either rouging or choice of planting material to be different from the control in Karemo variety in the 2003 to 2004 season (Table 30c). The rouging and choice of planting material treatments were either not significant ($P>0.05$) or the control was greater in weight (Table 30c). When compared to the resistant varieties, Karemo choice of planting material was different and had greater weight of tuberous roots than Migyera but was not significantly different ($P>0.05$) from MM96/4466. When the Karemo control was compared to the resistant varieties there was no significant difference ($P>0.05$) in the weights of tuberous roots per plot.

Table 30a. Effect of variety and management practice on weight of tuberous roots (kg/plot) at Karemo and Ugunja during the 2002 to 2003 season

		Management practice [z,y]				
Site	Variety	1	2	3	4	Mean
Karemo	MM96/4466	63.9	53.6	57.3	53.3	57.1a
	Migyera	46.2	42.6	37.9	26.8	38.4b
	Karemo	35.8	24.9	16.9	19.6	24.3c
	Bukalasa 11	32.8	29.4	31.3	14.0	26.9bc
	Mean	57.1	37.6	35.9	28.4	
	Variety $LSD_{0.05}$	12.5				
	Management $LSD_{0.05}$	NS				
	Interaction $LSD_{0.05}$	NS				
	CV (%)	27.8				
Ugunja	MM96/4466	62.7	51.5	69.2	61.4	61.2a
	Migyera	40.6	47.5	42.8	34.4	41.3b
	Karemo	23.0f	25.5f	11.8g	16.3g	19.2d
	Bukalasa 11	28.4	30.7	32.4	31.9	30.8c
	Mean	38.7	38.8	11.8	16.3	
	Variety $LSD_{0.05}$	8.0				
	Management $LSD_{0.05}$	NS				
	Interaction $LSD_{0.05}$	NS				
	CV (%)	22.0				

[z]1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.
[y]Values not followed by a letter or followed by the same letter within each factor and site are not significantly different at $P\leq 0.05$.

Table 30b. Effect of variety and management practice on weight of tuberous roots (kg/plot) at Karemo and Ugunja during the 2003 to 2004 season

Site	Variety	Management practice [z,y] 1	2	3	4	Mean
Karemo	MM96/4466	32.9	32.8	30.2	29.7	31.4a
	Migyera	17.2	16.8	17.2	14.7	16.5b
	Karemo	8.5e	29.1d	15.3e	14.2e	16.8b
	Bukalasa 11	21.1	23.6	21.9	16.7	20.8b
	Mean	19.9	25.6	21.1	18.8	
	Variety $LSD_{0.05}$	7.4				
	Management $LSD_{0.05}$	NS				
	Interaction $LSD_{0.05}$	NS				
	CV (%)	24.8				
Ugunja	MM96/4466	24.4	22.6	21.3	18.2	21.6a
	Migyera	20.6	34.9	15.9	24.9	24.1a
	Karemo	3.8i	24.4g	4.8i	15.3h	12.1b
	Bukalasa 11	6.9	17.6	7.9	10.3	10.6b
	Mean	13.9e	24.5d	12.5e	17.5e	
	Variety $LSD_{0.05}$	6.8				
	Management $LSD_{0.05}$	6.8				
	Interaction $LSD_{0.05}$	NS				
	CV (%)	22.9				

[z]1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y]Values not followed by a letter or followed by the same letter within each factor and site are not significantly different at $P \leq 0.05$.

Table 30c. Paired t-test comparison of weight (kg/plot) of tuberous roots for different varieties and management practice at Karemo and Ugunja during the 2003 to 2004 season

Variety	Management practice[z]	Tuberous roots	Management practice	Tuberous roots	t-value	Significance[y]
Karemo	1	6.2	4	14.8	-3.56	**
Karemo	2	26.8	4	14.8	5.12	***
Karemo	3	10.1	4	14.8	-1.37	NS

Management practice	Variety	Tuberous roots	Variety	Tuberous roots	t-value	Significance[y]
2	Karemo	26.8	MM96/4466	25.7	0.23	NS
2	Karemo	26.8	Migyera	16.6	2.52	*
4	Karemo	14.8	MM96/4466	23.9	-1.38	NS
4	Karemo	14.8	Migyera	19.8	-0.9	NS

[z]1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y]NS, *, **, ***, indicate not significant, significant at $P = 0.05$, $P = 0.01$, and $P = 0.001$, respectively.

(d) Harvest index

Harvest indices (HI) were calculated only for the second season (2003 to 2004), and were significantly ($P<0.05$) different for variety, but not for management practice effects (Table 31). Harvest indices were highest and equal for MM96/4466, Migyera and Bukalasa 11 at the two sites and lowest for Karemo. There was no significant ($P>0.05$) effect of variety by management practice interaction on HI at either site (Table 31).

Table 31. Effect of variety and management practice on harvest index per plot at Karemo and Ugunja during the 2003 to 2004 season

Site	Variety	Management practice [z,y] 1	2	3	4	Mean
Karemo	MM96/4466	0.5	0.5	0.5	0.5	0.5a
	Migyera	0.5	0.5	0.5	0.5	0.5a
	Karemo	0.3	0.3	0.3	0.2	0.3b
	Bukalasa 11	0.5	0.5	0.3	0.5	0.5a
	Mean	0.4	0.5	0.4	0.4	
	Variety $LSD_{0.05}$	0.1				
	Management $LSD_{0.05}$	NS				
	Interaction $LSD_{0.05}$	NS				
	CV (%)	7.9				
Ugunja	MM96/4466	0.5	0.6	0.6	0.5	0.6a
	Migyera	0.6	0.5	0.5	0.6	0.6a
	Karemo	0.3	0.3	0.3	0.3	0.3c
	Bukalasa 11	0.5	0.5	0.5	0.3	0.5b
	Mean	0.5	0.5	0.5	0.5	
	Variety $LSD_{0.05}$	0.04				
	Management $LSD_{0.05}$	NS				
	Interaction $LSD_{0.05}$	NS				
	CV (%)	7.7				

[z]1 = roguing once at 12 weeks after planting, 2 = choice of CMD-free stems as planting material, 3 = combination of roguing and choice of planting material, and 4 = control.

[y]Values not followed by a letter or followed by the same letter within each factor and site are not significantly different at $P \leq 0.05$.

CHAPTER FIVE
DISCUSSION

5.1. Experiment 1. Survey of Cassava Mosaic Disease and its Whitefly Vector

Results from interviewed farmers' showed that CMD is probably the most serious constraint to production of cassava, which is consistent with previous statements on the CMD pandemic in Kenya (Legg et al., 1999b). Continued use of CMD-susceptible varieties and the high incidence of CMD in cuttings used for new plantings facilitate the continued presence of damaging levels of CMD in western Kenya, where the main mode of CMD transmission was through infected cuttings. Maintenance of cassava plants in a relatively clean state could involve starting with clean (disease-free) planting materials, roguing and other phytosanitary measures.

The greatest proportion of farmers noticed CMD between 1997 and 2001, which is in agreement with previous findings as being the peak-period of the current pandemic in western Kenya, and when an overall incidence of 89% was reported (Legg and Ogwal, 1998; Obiero et al., 2001). The situation has changed considerably since that time and the incidence is currently about 50% according to the surveys carried out in this study.

The area under cassava declined due to inadequate planting material that were devastatingly affected by the CMD pandemic, and probably because farmers were still recovering from effects of the pandemic and could not grow as much cassava as they would have liked to grow (Odenya et al., 2003). Results indicated that farmers are not using the traditional approach of cultivating and recycling planting materials, but are being forced by the pandemic to look for external sources such as neighbours and relatives.

The most widely grown cassava varieties were landraces, which are mainly preferred because of their 'sweetness' and good boiling (cooking) properties for consumption as '*ateda*'. Most of the '*mogo*' varieties are long-term and can store well in the ground to allow piecemeal harvesting, beginning at 9 months and continuing for up to two years or even longer, after planting. This is one of the reasons why cassava is considered to be a key food security crop in western Kenya and in parts of Uganda (Otim-Nape et al., 1998).

Farmers generally lack knowledge and awareness on improved CMD-resistant varieties, and hence continue to grow local landraces that are CMD-susceptible. Continued growing of susceptible varieties is probably also because of positive attributes other than CMD-resistance, or

because farmers cannot get resistant varieties. Only a small proportion of farmers have heard of resistant varieties; an even smaller proportion of those that had heard planted them. This number increased in 2004 probably because the campaign to pass on this information has been succeeding progressively over the years, as more farmers are reached (H.M. Obiero, personal communication). The notion that some varieties are poisonous due to cyanogens is a major challenge to the adoption of improved varieties. It is noteworthy that the requirement for resistant varieties in western Kenya is overwhelming, and demand exceeds the capacity of KARI and collaborators to supply. This observation concurred with results in the adoption study done by Odenya et al. (2003) on the impact of resistant varieties in the management of CMD.

The resource-poor small-scale farmer has adopted intercropping as a production system to reduce the risk of crop failure, obtain production at different times of the year, and ensure food security. Farmers are also trying to make the best use of available land and labour resources to provide their families with a balanced diet. Other sources of carbohydrates contribute to providing primary caloric components and that is why maize is a common intercrop, whereas sweet potato is an alternative crop to cassava.

Severity in western Kenya was mild to moderate; severity in post-pandemic Siaya District was also not high despite high CMD incidence. Symptom severity reduction is normally enhanced further when farmers choose planting materials infected with mild strains of EACMV-UG that seem to provide some kind of cross protection against severe strains of the same virus (Owor et al., 2004a).

The total incidence increased for all Siaya District divisions, except Ukwala and Ugunja in 2004; the survey also revealed more frequent occurrences of improved CMD-resistant varieties in these divisions, which are less affected by CMD. The absence of whiteflies in Rift Valley province in October 2003 possibly explains why all the infection in this region resulted from diseased cuttings and none from whiteflies at the time of the survey.

Whitefly data indicated that most of western Kenya could now be in a post-pandemic situation (Sseruwagi et al., 1998). However, it is possible that if the survey were done during a different time of the year (season), the results would be different. This was the case with the second survey in Siaya District, when there was a big increase in whitefly population just before the rainy season (March 2004), unlike the previous survey (August 2003). However, despite the

increase in whitefly population at the time of the survey, whitefly infection was lower in each division of Siaya.

Correlation analysis results revealed positive relationships between CMD incidence and *B. tabaci* abundance. This result was as expected because this whitefly is the only known vector of CMD. Whiteflies are usually directly related to the rate of CMD spread (Legg and Raya, 1998), and hence the low number of whiteflies observed is consistent with the limited CMD spread observed in the four surveys.

Dual ACMV and EACMV-UG infection are more damaging than single virus infection (Harrison et al., 1997; Pita et al., 2001). Results from the PCR diagnoses indicated that EACMV-UG continues to be widespread throughout western Kenya. However, mixed infections or single infections with other CMGs were less frequent. As elsewhere, EACMV-UG appears to have displaced the originally prevalent ACMV. It was assumed the mixed-infection plants, initially frequent at the 'front' of the pandemic (Harrison et al., 1997), were so severely diseased that farmers select them out. Results from Uganda indicate that single-infection plants have a much lower virus concentration than mixed-infection plants (Harrison et al., 1997). The currently predominant single-infection plants in western Kenya, as evidenced by results of the current survey, accounted for the lower rates of whitefly transmission.

The presence of a large proportion of CMD-susceptible landraces in western Kenya partly explains the higher incidence of CMD. In Western Province, Bukalasa 8 and Bukalasa 11 are widely grown. They are moderately susceptible and this combined with widespread cultivation of resistant varieties explains the slightly lower incidences in this province. Improved varieties recorded included IITA ones such as TMS 30572, released in Uganda as Nase 3 or Migyera, TMS 30337 released in Uganda as Nase 2, and SS4 released in Uganda as Nase 4 and found especially in Teso and Busia districts. Their increasing presence, especially in Western Province, provides evidence that management programmes, involving multiplication and distribution of CMD-resistant varieties, are having a positive impact in lowering incidence and severity (Obiero et al., 2004).

5.2. Experiment 2. Measurement of Cassava Mosaic Disease Inoculum Pressure in Siaya District

The presence of CMD at some point, in both tested varieties is an indication that neither of these varieties is immune to the disease, and that resistant varieties can also become infected.

However, the low incidences in resistant varieties have been known to reduce or completely disappear with time, as the virus is not completely systemic in these varieties (Rossel et al., 1992). A difference in incidence in the same variety in different areas suggests differences in the rates of spread by the whitefly vector, as evidenced by the final incidence of 48% at Ukwala and 12% at Yala for Bukalasa 11 in the 2002 to 2003 season. Otim-Nape et al. (1994a), working with Ebwanatereka — a CMD-susceptible cultivar in Uganda — observed similar results with an incidence of 81% in Masindi, but only 32% in Kasese. The authors attributed the variation to differences in number of whiteflies and/or whitefly activity, seasonal factors, as well as the overall inoculum pressure of the diverse areas.

Although both Bukalasa 11 and Migyera showed an increase in severity over time, Bukalasa 11 generally showed higher severity possibly because of its higher susceptibility to CMD. Susceptible varieties are more easily infected and usually have high disease incidence. This, however, does not mean that they always have high sensitivity, more severe symptoms, or virus titre. There are cases where less susceptible varieties express low incidence, but higher severity in the plants that are diseased (Fargette et al., 1996). However, despite the low severity and incidence in Migyera, its whitefly population was significantly higher than in Bukalasa 11, indicating that improved (CMD-resistant) varieties have resistance to the virus, but not to whitefly infestation (Fondong et al., 1997).

The current trial was planted with clean cassava cuttings and hence the samples extracted from infected Bukalasa 11 plants were due to current season's infection by viruliferous whiteflies, which brought the virus into experimental plots from infected plants in surrounding fields. The current study has shown that EACMV-UG is the predominant CMG in the different divisions of Siaya District. The average symptom severity index at all times of assessment was between 2.0 and 3.0, implying that the symptoms were not very severe. This is probably due to the prevalence of mild forms of EACMV-UG. It has been shown in a study of CMGs occurring in post-epidemic Uganda that EACMV-UG occurs with almost equal frequency in both mildly and severely diseased plants (Sseruwagi et al., 2004b), and not exclusively in severely diseased plants, as was the case earlier (Pita et al., 2001). The relatively low rate of infection in Migyera was evident in all the divisions tested. Furthermore, as plants grew older symptom severity and incidence sometimes decreased, suggesting that mature plants of resistant varieties acquired resistance over time (Fargette and Vie, 1995).

In the current study, whiteflies not only brought the disease into the crop through primary infection, but also through secondary infection from infected to healthy plants within the same plant generation and during the same growing season. The rate of spread of CMGs has been shown to depend on the size of the vector population, which as it increases the disease incidence also increases about a month later. Field observation by Fargette et al. (1994) and Fondong et al. (1997) proved that the average incubation period between infection and appearance of symptoms is about one month.

The highest adult whitefly population in the current study was recorded at 4 to 5 MAP, while the highest disease incidence and severity score were observed at 6 to 7 MAP, although the two variables were not correlated. The highest whitefly populations in Siaya District occurred when temperatures were highest in the January to March period that precedes long rains, concurring with earlier observations (Legg, 1995). Studies of *B. tabaci* population dynamics on cassava consistently suggest that abundance coincides with periods of high temperatures and rapid growth of cassava (Dengel, 1981; Legg et al., 1997).

A common feature with much of Kenya and sub-Saharan Africa is that many smallholder farms characterise agricultural regions. Siaya is one of the poorest areas of Kenya with over half of the household living in absolute poverty and land is the major resource for earning income (Mwagore, 2002; Onyango, 2003). The small farms coupled with population pressure and the wood-fuel crisis leads to increased deforestation, leaving few trees in the general area to act as windbreaks for hampering whitefly movement. This fact explained why the current study contrasted with Ugandan trials conducted by Legg et al. (1997) in forested zones to develop multiple regression models, relating number of *B. tabaci* and inoculum pressure index to final disease incidence. The Legg et al. (1997) study revealed important differences in rates of CMD spread in sites that were in different ecological zones. The methodology used for this trial provided a relatively straightforward means of measuring CMD spread into initially disease-free cassava plantings. Unlike the Legg et al. (1997) study, however, the experiment in western Kenya did not reveal a clear relationship between CMD spread and inoculum pressure or whitefly abundance. The final CMD incidence could, therefore, not be predicted from the *B. tabaci* abundance and inoculum availability index. A possible explanation for this result could be that the trial sites (divisions) were all in relatively open environment (Mwagore, 2002; Onyango, 2003).

Environmental effects outside those considered in the scope of this study such as the occurrence of only less virulent strains of CMGs and interactions between CMD and other pests also probably had a role in the departure of the observed results from the expected results. There is evidence of more and less virulent strains of EACMV-UG in Uganda (Owor, 2002; Sseruwagi et al., 2004b). The Karemo site, which had the highest inoculum availability index in the 2003 to 2004 season incidentally gave the lowest final incidence and also had a very low whitefly population. This is possibly because of the 100% incidence of cassava green mite (CGM) that was observed at this site and the fairly high severity score of between 4.0 and 5.0 recorded in both varieties. Fishpool and Burban (1994) reported that the presence of CGM on the underside of leaves discouraged oviposition of *B. tabaci*. The deleterious effects of CGM are likely to have had an important effect on the biology of CMD and its whitefly vector. This is apparent from the inverse relationship established between the populations of *B. tabaci* and the severity of CGM damage to leaves of the cassava variety Bao in Uganda (Legg, 1994). It is also likely that the effect of CGM on the overall condition and growth rate of shoot tips influences susceptibility to CMG infection, as well as how the CMGs are acquired and transmitted to uninfected plants (Thresh et al., 1994a).

With continuation of CMD pandemic spread, there has been a general reduction in CMD inoculum pressure, due to reduction of the area planted with cassava, increasing prevalence of improved (CMD-resistant) varieties, as well as emergence of somewhat tolerant local varieties and less virulent viruses. These changes have led to use of the term 'post-epidemic' to describe the current state of CMD in Uganda, parts of western Kenya, and other areas where the pandemic has passed through (Otim-Nape et al., 2000; Sseruwagi et al., 2004b).

In this Siaya study in a 'post-pandemic' area, the moderately susceptible Bukalasa 11 gave incidences that ranged from 4% to 68%; at half of the sites, the incidence was over 40%. The change in performance of Bukalasa 11 as the CMD pandemic has progressed, provides a good example of the shifts in balance that can occur between a pathogen and its host during co-evolution. In the 1940's, Bukalasa 11 was considered resistant, while currently it is considered moderately susceptible to CMD (Legg and Thresh, 2000). Legg and Thresh (2000) compared the epidemiology of Bukalasa 11 during the epidemic, pre-epidemic and earlier years. In Kizimbani-Zanzibar (1938-1939), whitefly infection was 19% and CMD increment was 34 in multiple infection units (MIU). In Serere-Uganda (1942-1943), whitefly infection percentage and CMD

increment in MIU were both 2.0. In Namulonge-Uganda (1989-1990) prior to the epidemic, whitefly infection and CMD increment were both nil. In Migyera-Uganda (1990-1991) during the epidemic period, whitefly infection was 75% and CMD increment was 139 MIU. The trials in Zanzibar and Serere were planted where CMD spread was expected to occur readily and spreader rows of heavily diseased local cultivars were used. Whitefly incidence in Serere was quite low, despite the CMD problem in Uganda at that time, and was more likely due to the increased planting of infected propagules than due to any change in inherent virulence of the virus or whitefly vector (Jameson, 1964). The epidemic situation in Uganda (1990-1991) contrasted markedly with that in Uganda (1942-1943), emphasizing the exceptionally rapid rates of spread that are such a feature of the current pandemic. The data presented by Legg and Thresh (2000) also suggests that for a cultivar such as Bukalasa 11, the pre-epidemic situation recorded at Namulonge was comparable to that recorded during the CMD 'crisis' of the 1940's in Uganda (Jameson, 1964; Legg and Thresh, 2000).

Pre-pandemic and earlier epidemiology experiments in western Kenya concluded that infection pressure was extremely low and there was little or no spread of CMD. Final incidences after one year's exposure of initially disease-free local landraces in Busia district ranged from 0% to 4.3% (Bock, 1983). Similar experiments with three susceptible Brazilian varieties also gave final incidences of 2%, 3% and 10% (Bock, 1994). Surveys in western Kenya during the epidemic reported an overall incidence of 89% (Legg and Ogwal, 1998). The moderate symptom severity index in this Siaya trial contrasted with the high indices recorded during the epidemic period. This result suggests the presence of a mild strain of EACMV-UG, although this CMG has been reported to prevail during both the epidemic and 'post-epidemic' times (Legg and Thresh, 2000; Owor et al., 2004a).

5.3. Experiment 3. Effects of CMD and Variety on Growth and Yield of Cassava

Cassava mosaic disease (CMD) negatively influences growth and yield of cassava depending on variety susceptibility and disease severity. Cassava mosaic disease injury was least in Migyera, which is an improved CMD-resistant variety. In this variety, although mosaic symptoms were expressed, leaves showed no distortion, sustained little or no damage, and severity remained fairly constant or disappeared. In the CMD-susceptible varieties Bukalasa 11 and Karemo, the effects were severe and characterized by reduced leaf size and leaf distortion.

There was also stunted growth in Bukalasa 11 and elongated plant growth in Karemo. Migyera's response in the current study can be explained by the findings of Njock et al. (1992), which showed that CMD does not become fully systemic in resistant genotypes; thus, there was a tendency of Migyera's infected plants to become symptom-free with time. Plants of moderately resistant and susceptible genotypes recovered much slower than those of resistant ones. This phenomenon is known as recovery, which in cassava is attributed to incomplete systemicity (localized distribution) of causal viruses; consequently, whole branches or individual shoots that are free of any detectable virus and symptoms occur, thereby providing uninfected cuttings (Fargette et al., 1994). This self-cleansing phenomenon is important in restricting progressive build-up of disease that could otherwise occur during successive cycles of vegetative propagation (Thresh et al., 1998b).

Symptoms were severe in the initially diseased plants, possibly because the plants were affected at an early stage of growth; plants infected late sustain little or no damage (Calvert and Thresh, 2002). There is abundant evidence in studies reported by Thresh et al. (1994a) from 12 countries that CMD decreases growth and yield of many locally-grown varieties and that losses sustained are greatest when plants are more severely infected from the outset. In diseased plants of the CMD-susceptible varieties, poor plant growth resulted in few tuberous roots, low root weight, and low harvest index, indicating poor accumulation of assimilates in the storage organs.

All cassava mosaic geminiviruses (CMGs) whether single or mixed have negative effects on symptom severity, growth and yield of CMD-susceptible cultivars. Both mild and severe strains of ACMV and EACMV have been reported (Pita et al., 2001). It has been shown that some virus strains or strain-combinations cause more severe symptoms and decrease in growth and yield than others (Owor et al., 2004a). Mild strains usually cause less severe effects on plant growth and yield loss than severe strains (Owor et al., 2001; Owor et al., 2004a). It is possible that diseased plants in the yield loss study were affected by severe strains of EACMV-UG.

In the current study, CMD significantly reduced biomass of susceptible Karemo and Bukalasa 11 varieties, compared to the resistant Migyera. The reduced biomass was attributed to fewer leaves, which eventually resulted in small-sized plants with shorter stems and depressed yields (Owor et al., 2004b). Yield of CMD-affected plants decreases because of reduction in photosynthetic area (leaves) and plant growth, in general. Ayanru and Sharma (1982) showed that for CMD to reduce yield significantly it would have to disrupt the plant's metabolic

activities and photosynthetic processes. Thus, reduction in yield as symptom severity increases is related to the degree to which metabolic and photosynthetic processes are affected; reduction in these processes produces a direct negative effect on tuberization (Otim-Nape et al., 1994b).

The yield losses for Bukalasa 11 and Karemo in the current study concurred with previous reports that CMD can cause 80% to 100% yield loss in individual plants, depending on the sensitivity of the variety (Thresh et al., 1994a), the stage when infection occurs (Fargette et al., 1988), and the severity of symptoms (Otim-Nape et al., 1994b). The significant reductions in yield of the susceptible varieties in the current study concurred with results of Lwole (2000), in which resistant varieties had superior performance, while CMD significantly reduced yield of CMD-susceptible 'relic' cassava varieties. Other studies assessing a wide range of genotypes have shown that those that develop mild symptoms tend to out-yield those with severe symptoms (Hahn et al., 1980). Experiments carried out in Madagascar indicated that plants with mild symptoms out-yielded symptom-free plants and the effect was attributed to improved partitioning of assimilates between aboveground parts and tuberous roots (Cours et al., 1997). A similar study by Owor et al. (2004b) also revealed that plants infected by mild strains of CMG's expressed less severe symptoms and out-yielded plants that were initially healthy, but subsequently became severely diseased. These findings provide a possible explanation for the differences in severity of Bukalasa 11 and Karemo plants and hence the yield differences. Some of the mildly diseased plants had a low score of two and yielded highly. The more severely affected score four and five, especially in Bukalasa 11 yielded very poorly in comparison. Diseased Migyera out yielded diseased Bukalasa 11 and Karemo, this is largely because of resistance. Migyera being a resistant variety has low virus titres, its growth and yield is therefore less affected by CMGs.

The significant, negative, linear relationship between symptom severity and yield variables revealed their inter-dependence and the fact that good performance in growth results in high final yield (Calvert and Thresh, 2002). The findings in the current study are similar to those of Lwole (2000) in western Kenya and Owor et al. (2004b) in Uganda. The researchers showed that leaves, stems, petioles and storage organs are important components of yield; factors interfering with their normal growth also affect yield. Great reduction of growth and yield, as symptom severity intensifies results because CMD effects are proportional to the degree of symptom severity (Osiru et al., 1999). The current study proved that CMD reduced plant growth potential, and

hence the final yield (number and weight of tuberous roots), as an indirect result of reduced plant growth (Bock and Guthrie, 1978; Seif, 1982; Lwole, 2000). A more rigorous analysis of the inoculum pressure data might have been made by using the nested design approach. Although this would have improved the statistical validity of the result. It is unlikely to have led to any changes in the general outcome in terms of significant versus non-significant conclusions.

5.4. Experiment 4. Effects of Cultural Methods and Resistance in the Control of CMD

There were marked differences in CMD symptom expression among varieties, with CMD-resistant varieties having less conspicuous symptoms. MM96/4466 consistently expressed no symptoms most likely because it did not get infected at all. Migyera, though resistant, showed some mild symptoms at different times, and the proportion of plants that became infected depended on the site, probably because of the difference in prevailing inoculum pressures. Diseased plants were mainly in the severity score category 2.0; however, there was a lot of recovery and most of the diseased plants eventually showed no symptoms. This result concurred with that of Gibson and Otim-Nape (1997), where plants that had previously expressed CMD symptoms produced a sequence of symptomless leaves. This same phenomenon could also explain the slight drop in symptom severity of Karemo and Bukalasa 11 at different times during the course of the current study. In the second season sometimes cuttings from plants that were diseased in the first season produced symptomless plants especially with Migyera. The phenomenon of reversionis a common feature of resistant varieties though it has also been reported for CMD-susceptible varieties (Fauquet and Fargette, 1990; Owor et al., 2004a).). It is important to note that the absence of symptoms on shoots where substantial reversion has occurred does not mean complete absence of the causal virus (Pacumbaba, 1985; Fondong et al., 2000).

Variety Karemo was generally infected earlier; however, symptom severity remained fairly constant and hence there was no marked change in the distribution of plants in the different severity score categories over time. In Bukalasa 11, the severity score distribution changed markedly over time, and showed mostly clean plants at the beginning and plants in severity score categories 3.0 and 4.0 to 5.0 at the end of assessment. This resulted in increased differences in symptom expression of diseased plants in the two varieties over time at the two sites, especially in the second season (2003 to 2004). Variety Karemo at the Karemo site in the 2003 to 2004

season started out diseased, but the symptoms expressed were not severe; thus, variety Karemo contrasted with Bukalasa 11 at the same site that started out healthy, but eventually showed more plants with higher severity scores. This result suggests the possibility of occurrence of cross protection in mildly diseased plants of CMD-susceptible varieties, whereby initially healthy plants exhibit higher sensitivity to new infections with more virulent strains of CMD than already diseased plants (Owor et al., 2004a).

In CMD-susceptible varieties such as Karemo, choice of planting material was only partially effective in reducing CMD, because even clean materials became rapidly infected with CMD upon sprouting at both sites, and the remaining clean material in the rogued treatments were affected by CMD soon after the roguing exercise. Indiscriminate roguing of diseased plants of variety Karemo greatly reduced plant population. In choice of planting material treatment for Bukalasa 11, disease symptom expression in the early months was quite low. Since symptom severity in Migyera — a variety with substantial reversion ability — was consistently less than that of CMD susceptible varieties at the same site, roguing and choice of disease-free material is probably not a justifiable practice in farmers' fields with such a variety.

Disease incidence was highest in the CMD-susceptible varieties and lowest in the CMD-resistant varieties during both seasons. Therefore, varieties MM96/4466 and Migyera are good components of integrated disease management approach, because resistance prevents plants from becoming affected (Obiero et al., 2003). These varieties have proved resistant to all CMG strains and mixtures that have been identified to date (Legg, 1999). The same CMGs have been known to elicit rapid spread and high final disease incidence in local landraces, as was the case with Karemo and Bukalasa 11 in the current study.

In the first season (2002 to 2003) unlike in the second season (2003 to 3004), virus-free cuttings were used for all plantings and plants were not infected in the early stages of crop growth. This result was especially evident when final disease incidences for the two seasons were compared for the CMD-susceptible varieties Karemo and Bukalasa 11; incidences were much higher in the control plots in the second season than in the choice of planting material plots. This observation concurred with results of earlier experiments in Kenya, which showed that planting virus-free cuttings lowered disease incidence (Bock, 1983). Roguing also reduced disease incidence compared to plots in which it was not done. However despite this reduction, final disease incidence in variety Karemo in the current study concurred with those reported by

Colon (1984) in Ivory Coast for local CMD-susceptible varieties, which exhibited high (77% to 78%) final incidence in rogued and non-rogued plots.

Karemo site was partially isolated by a small forest of trees, which were felled by the farmer towards the end of the first season. Cassava fields around this site were few and mostly had mildly diseased Karemo plants. Cassava fields around the Ugunja site were numerous and had mildly to severely diseased plants of variety Adhiambolera. This variation in neighbouring features could have affected the general inoculum pressure of the two sites differently and hence the disease incidences. Karemo site exhibited low disease incidences compared to Ugunja; the incidence at Karemo was low in the first season, compared to the second season. The differences concurred with the pattern reported earlier that CMD incidence in different areas is influenced by a range of factors, including the intensity of cassava crops grown (Fargette and Thresh, 1994). Changes in the disease, vector, and crop pathosystems also affect disease pressure of a site and can give rise to a highly dynamic disease situation (Legg et al., 1997).

Varieties differed in abundance of *B. tabaci*, but as expected management practices did not have a significant effect on the population dynamics of this insect pest. Results in the current study concurred with those of earlier studies that suggested that *B. tabaci* are more abundant when temperatures are high or when cassava is rapidly growing (Legg, 1999). Relationship between number of CGMs and damage or adult *B. tabaci* has been shown to be inverse (Legg, 1995), and this could explain the reduced whitefly population in Migyera at Karemo in 2003 to 2004 season. The highest whitefly population was recorded from the middle of the two seasons and in the CMD-susceptible Karemo and Bukalasa 11 varieties. This result concurred with previous reports by Fondong et al. (2000), which showed concomitant increase in population of the vector and disease incidence, and the average incubation period between infection and symptom expression to be about one month.

Yields were greater for the CMD-resistant varieties; however, the moderately susceptible Bukalasa 11 consistently resulted in lower yields than the other varieties. It is encouraging that the CMD-resistant germplasm selections have shown good levels of resistance and some, such as MM96/4466, appear almost immune to infection. This variety consistently gave higher yields than the rest. A critical constraint to use of such varieties, however, is the slow pace with which they can be multiplied and distributed to farmers. Thus, integrated approach, encompassing planting of CMD-susceptible varieties that have shown potential to produce substantial yields in

spite of being affected, should continue to be considered. Such varieties include Karemo, which gave slightly higher yield, compared to improved resistant varieties in the second season despite its high incidence of infection. This was especially true in the choice of planting material management practice. Initially mildly infected plants have been shown to out-yield initially healthy plants in the CMD-susceptible variety Ebwanatereka in Uganda (Owor et al., 2004b). In CMD-susceptible varieties such as Karemo, choice of planting material leads to improved yields over a period of two seasons, when compared to the control. Thus, the impact of phytosanitation measures can only be expected to become apparent in the second season.

Yields were generally higher in the first season than in the second season. Re-use of land is partly a consequence of population pressure that has led to scarcity of land and farmers generally do not add any nutrients or fertilizers to their cassava farms. Such practices evidently negatively affect cassava production.

The current study has shown that a yield penalty is incurred when phytosanitation measures are not practiced in CMD-susceptible varieties. Delaying infection-effects through choice of clean planting material results in higher number and weight of tuberous roots, even if the final disease incidence is the same. Farmers usually have a general and understandable reluctance to remove any plant that might contribute to yield (Thresh et al., 1998a). The current trial has also shown that indiscriminate roguing of diseased plants of CMD-susceptible varieties such as Karemo could be counter productive as it leads to an unacceptable decrease in plant stand and hence final yield. This is especially so where much spread occurs. To get the most benefits from phytosanitation and to increase farmers' adoption of the techniques, plants are inspected when symptom expression is conspicuous and tagged or marked with paint. The plants are then retained for the farmer to benefit from the current season's yield, but rejected later when cuttings are collected for subsequent plantings, as is done in India (Malathi et al., 1987).

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1. CONCLUSIONS

The conclusions described below were drawn from the four studies conducted in the current research. The conclusions varied depending on the specific aspect under study as follows:

6.1.1. Experiment 1. Survey of Cassava Mosaic Disease and its Whitefly Vector

- The decision to plant cassava is made mainly by women, who then obtain planting materials and provide the bulk of labour for cassava production in western Kenya.
- There is great potential for phytosanitation to work in western Kenya given that currently few farmers are practising it.
- EACMV-UG continues to be the most frequently occurring CMG in western Kenya.
- The disease seriously affected many farmers, and consequently they abandoned cassava growing which resulted to reduced sources of CMD inoculum and the cassava whitefly population. This combination of factors has led to the current low levels of CMD spread in the mostly 'post-epidemic' western Kenya.

6.1.2. Experiment 2. Measurement of CMD Inoculum Pressure in Siaya District

- The incidence and severity in different areas of Siaya District is relatively uniform, low to moderate, and differences depend largely on the susceptibility of the variety grown.
- Results of the current study in western Kenya show that the rapid rates of spread during a pandemic situation possibly reduce to moderate rates in post-epidemic situations.
- Inexpensive visual analysis of plants in the field, as opposed to the expensive serological assays, is a reliable criterion for choosing of CMD-free planting material from susceptible varieties. Since 100% of the time apparently CMD-free plants sprouted with no symptoms; thus, farmers can easily and cheaply adopt this practice. This is not as reliable for resistant varieties because of the recovery and reversion phenomena.
- Use of resistant varieties has the effect of decreasing the overall inoculum pressure and the incidence of infection.

- The relatively low inoculum pressure in western Kenya, as revealed by the Siaya District inoculum pressure trial presents an ideal opportunity and condition for obtaining virus-free stock plants through rigorous choice of planting material from moderately susceptible and resistant varieties.

6.1.3. Experiment 3. Effects of CMD and Variety on Growth and Yield of Cassava

- The effect of CMD on growth and yield of cassava plants depends on susceptibility of varieties. The better response of improved Migyera compared to susceptible Bukalasa 11 and Karemo confirmed the effectiveness of resistant varieties in management of CMD.
- Virus-free planting materials remain largely free of CMD in areas where there is minimal spread by whiteflies, resulting in substantial increase in growth and yield of moderately susceptible and resistant varieties.
- Cassava mosaic disease causes enormous losses in Bukalasa 11 and other local, susceptible varieties, because farmers have not ceased growing them.

6.1.4. Experiment 4. Effects of Cultural Methods and Resistance in the Control of CMD

- The current study confirmed that cassava mosaic disease-resistant varieties are clearly more effective and advantageous than phytosanitation and other methods in mitigating the effects of the cassava mosaic disease pandemic.
- Choice of planting material in CMD-susceptible varieties such as Karemo is beneficial, and yields of such varieties compare favourably with those of improved materials.

6.2. RECOMMENDATIONS

Basing on the fore-going conclusions, the following simple decision-making guidelines and recommendations can be drawn for the management of CMD. The recommendations are diverse and hence the best strategy should embrace integration so as to reap maximum benefits.

6.2.1. Experiment 1. Survey of Cassava Mosaic Disease and its Whitefly Vector

- Women should be the main targets during training sessions and distribution of cassava planting materials.

- The naive methods tried by farmers to control CMD confirm the need for farmers to be better informed about the disease, what it is and how it is spread.
- The 'post-epidemic' status of the disease in western Kenya and the high CMD incidence due mainly to the use of infected cuttings confirm the need to apply other management practices to augment resistant varieties.

6.2.2. Experiment 2. Measurement of CMD Inoculum Pressure in Siaya District

- Estimation of surrounding CMD needs to include a bigger radius because whiteflies can fly quite a long distance, as evidenced by the incidence of CMD even in sites that had an inoculum availability index of zero.
- Topographical and vegetation effects, which might be expected to influence the ease with which whiteflies move from surrounding cassava fields to a trial site should also be considered in future.

6.2.3. Experiment 3. Effects of CMD and Variety on Growth and Yield of Cassava

- Cassava mosaic disease severity and the large losses caused in commonly grown local varieties that are CMD-susceptible should be decreased indirectly at planting time through choosing mildly diseased, or clean planting materials.
- Undoubtedly, improved CMD-resistant varieties should be used to bring substantial benefits through decreasing losses caused by CMD.

6.2.4. Experiment 4. Effects of Cultural Methods and Resistance in the Control of CMD

- The logistical difficulties in multiplying and disseminating large quantities of improved CMD-resistant cassava stems to farmers, presents a clear need to investigate alternative CMD management means such as phytosanitation of varieties preferred by farmers.
- Development of a clearly defined and integrated approach to CMD management using phytosanitation should involve consideration of information on mild and severe strains of viruses and their symptom expression.
- There is a need for additional studies on a wider range of CMD-susceptible varieties in different agro-ecological zones, but particularly 'post epidemic' ones.

- Cassava mosaic disease management studies should involve collaboration with groups of farmers and extensionists in localities rather than just one isolated individual farmer, since the spread of CMD is mostly severe between and among cassava plantings.
- The acquired-resistance phenomenon, which develops as chosen clean planting materials, especially of moderately susceptible varieties matures should be exploited to achieve some degree of control through delay of disease onset.
- Phytosanitary measures should be kept simple to enable farmers adopt and practise them readily on a sustainable basis without the need for continued technical and logistical support.
- Phytosanitation including choice of disease-free planting is recommended for reducing incidence in 'post-epidemic' areas exhibiting low to moderate spread, low *B. tabaci* abundance and low inoculum pressure.
- Choice of disease-free or the most vigorous stems as planting material should be used as a CMD-management measure for CMD-susceptible varieties like Karemo in Siaya District.

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APPENDIX

Survey and Management of Cassava Mosaic Diseases in Siaya District

KM14/0690/02

Interview sheet for farmer number.....

Recorder.....

Division..... Location ..... Sub-Location..... Village .....

Farmer's gender..... Age group.....

Instructions: Tick or write appropriate answer

1. Source of planting material. *Relatives/ Fellow farmers/ Market/ Uganda/ KARI/ MoA*
2. Which family member sources? *Father/ Mother/ Children/ Other*
3. Who does the weeding, maintenance and harvesting of cassava crops?
4. What varieties have you ever grown?
5. When did you first notice cassava mosaic disease (CMD) on your farm?
6. What methods did you try to use for control?
7. Did you ever stop growing cassava? *Yes/ No.*
   If yes, what crop alternatives to cassava did you take up?.....
8. Was any selection of planting material done for the current crop? *Yes/ No.*
   If yes, based on what?.....
9. Have you ever practised rouging of diseased plants? *Yes/No.*
   If yes, how long after planting?.....
10. What % of your farm is now under cassava? *<25%, 25-40%, 41-75%, >75%.*
11. Have you intercropped? *Yes/No.* If Yes why? .....
12. Have you heard of resistant varieties from KARI and MoA? *Yes/No.* If yes, from whom? *Relatives/ Fellow farmers/ Local leaders/ KARI/ MoA.* Which varieties did you hear about?.....Did you plant any *Yes/ No.* If no, why not?.....
13. How do you harvest your cassava? *Once-over/ piecemeal.*
14. Is any form of postharvest technology used to keep fresh cassava longer? *Yes/ No.*
    If yes, what?.....
15. Any comments/interesting information?.....