THE OCCURENCE OF VIRUSES AND APHID VECTORS IN SMALL SCALE POTATO SEED PRODUCTION SYSTEMS AND THEIR EFFECT ON YIELD IN KENYA

BY

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A THESIS SUBMITED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP PROTECTION OF THE UNIVERSITY OF NAIROBI

2003

DECLARATION

This thesis is my original work and has not been presented for a degree in any University

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ACKNOWLEDGEMENT

I wish to thank my supervisors, Dr. F. Olubayo, Dr. R. Njeru and Dr. J.H. Nderitu under whose guidance the completion of this study was made possible.

I am also very grateful to the International Potato Centre (CIP) particularly Dr. Ramzy El-Bedewy and Dr. Modesto Olanya for the provision of some study materials used in the experiments

I would also like to thank the National Potato Research Centre (NPRC) and in particular the Director, Dr. Kabira for the provision of land and some certified seed for the on-station experiments and also for useful exchange of ideas on work at the station.

The support I also received from non-teaching staff especially entomology and plant pathology laboratory technologists in the department of Crop Protection in providing equipment and access to the laboratory whenever I needed it is highly appreciated.

I wish to express my deepest gratitude to the Rockefeller FORUM for Agricultural Research through the Principal Investigator of the project I was working on, Dr. Olubayo and the Collaborator Dr. Nderitu in the Department of Crop Protection, University of Nairobi for sponsoring my entire study in this MSc. course. Thanks also go to my employer, the Ministry of Agriculture for giving me study leave to undertake these studies.

Above all, I thank the Almighty God for it is only through Him that all this was made possible. Last but not least, I wish to thank the Christian fellowship especially the Kabete campus postgraduate Christian fellowship and the water supply home fellowship in Murang'a for their Prayers. I am very grateful for all this support and may God bless all who played any part in supporting my study through this MSc. programme.

DEDICATION

To my wife Anne Muthoni Maina and daughter Elizabeth Wanjeri Maina for their support and encouragement during my study in this programme.

To my parents for enabling me to reach this level of education.

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ABSTRACT

The Overall Objective of this study was to determine the incidence and distribution of Potato viruses, relationship to aphid vector population and effect of these virus diseases on yield loss and seed quality of different potato varieties in Kenya. The study was carried out in 3 phases, which were a field survey, on-farm monitoring and an on-station experiment on aphids and viruses.

A survey of potato viruses and their aphid vectors was carried out in three major potato growing areas, namely Tigoni in Kiambu district, Njabini in Nyandarua district and Molo in Nakuru district. Sixty seed farms (20 per district) were surveyed. Viral diseases were most prevalent in the Tigoni area (47.1%) followed by Njabini (25.6%) and Molo (25%). The most encountered single potato viral infection was potato virus S (PVS), (79.1%), followed by potato leaf roll virus (PLRV), (34.9%), potato virus Y (PVY), (8.5%) and potato virus X (PVX), (7.0%). The aphid populations, taken from 90 leaves per farm (30 plants, 3 leaves per plant, from top, middle and bottom positions) were highest in Tigoni area (average 73 per farm), followed by Njabini area (26 per farm) and lowest in Molo area (11 per farm). The most prevalent aphid species was *Aphis gossypii* (61.8%), followed by *Macrosiphum euphorbiae* (20.5%) then *Myzus persicae* (14.9%) and the least was *Aulacorthum solani* (2.8%). Bottom positioned leaves had the highest aphid populations (42.5%), followed by middle leaves (37.4%) and lastly top leaves (20%). There were statistically significant differences ($P<0.05$) in aphid populations at the different survey areas and also in the populations of the different aphid species, but there were no significant differences in aphid populations at the different leaf positions.

On-farm monitoring of the aphids and viruses for 2 seasons at 4 farms in the Tigoni area revealed a similar trend in aphid species and potato virus occurrence. Farmer management practices affected the number of aphids and the virus incidence on the potato crop. Farms where uncertified seed was used had, significantly higher virus incidence than farms where certified

seed was used. Farms where aphid control measures were practiced had significantly lower aphid populations than farms where no aphid control measures were practiced ($P<0.05$).

On-station field experiments done at Tigoni and Kabete stations also revealed that there were significantly lower aphid populations in plots where spraying with aphid control chemicals was done than in plots where there was no spraying for aphid control. Plots planted with certified seed potato had significantly lower virus incidence than plots planted with uncertified seed. There was a significant reduction in yields with increase in virus incidence at both sites. There was a significant decrease in potato yields with increase in aphid populations at Kabete but there was no significant relationship between aphid populations and yields at Tigoni. There was no significant relationship between the aphid populations and virus incidence at both Kabete and Tigoni, but it was clear that, as aphid populations increased, the virus incidence also increased at both sites. This trend suggests that, with time there is a possibility of a significant increase in virus incidence with increase in aphid populations.

The results of these studies show that, high aphid populations result in high virus levels leading to serious yield losses. Seed production in low altitude areas is under threat due to high aphids and virus levels. Using uncertified seed from markets also results in low yields due to viruses. It is therefore recommended that farmers should be taught proper control measures for aphids, together with other potato virus management practices such as use of certified seed and rouging virus symptomatic plants. This is necessary to reduce the virus disease spread in order to maintain good yields in seed and ware potato production systems in Kenya.

CHAPTER ONE

INTRODUCTION

1.1 The Potato Crop

Potato (*Solanum tuberosum* L) is the world's fourth most important food crop after wheat, rice and maize (CIP, 1996). It is also the world's most grown vegetable followed by tomato (Ruben, 1980). Potato is considered native to Central and Southern America. The cultivated potato probably originated in the Peru-Bolivia region about 8000 years ago. The crop was brought to Kenya from Europe during the late nineteenth century. Because of its origin, the potato in Kenya is generally referred to as English or Irish potato. Since its introduction in Kenya as a food crop for European farmers, the potato has experienced a tremendous expansion in production and utilization as food (Durr and Lorenzl, 1980).

In Kenya, Potato is mainly grown in the densely populated highlands (1500 to 3000m above sea level), where temperatures and rainfall are conducive to its cultivation. Its importance in recent years has grown rapidly and it is now the second most important food crop after maize in terms of production volume (Ng'ang'a *et. al.*, 1994; Anon., 2002). The crop serves both cash and subsistence needs of the farmers and is a staple food for many rural and urban families. It is grown on an estimated hectarage of 108,100 in the country with a total production of 670,300 tons (Anon., 2002). The average plot size of the farms planted with potatoes is less than 0.5ha. (Njuguna, 1997). While 70-75% is used directly for consumption in the farm, the rest contributes to about 2% of the gross value of the marketed agricultural produce (Maingi, 1992). Although it is an important crop, the national average of 4.4 tons/ha is low compared to the world average of 17tons/ha in developed and 13 tons/ha in developing countries (FAO, 1992; FAO, 1995). It is possible to realize 40tons/ha under research station conditions in the country (Lung'aho *et. al.*, 1997). The increased demand for potatoes as a staple food in rural areas and as a 'fast' food (French fries and potato crisps) in urban centres, calls for increased production in the farmer's fields.

1.2 Potato Production Constraints

The basic problem facing potato production in Kenya is low yields due to diseases and insect pests (Kinyae *et. al.*, 1994). Although the total land under potato cultivation has increased four-fold between 1965 (27,000 ha.) and 2000 (108,000 ha.) (Anon., 2002) yields per unit area have

continually declined (Barton *et. al.*, 1997). The low national average yield is mainly due to lack of adequate and affordable certified seeds that are within the economic reach of the small-scale farmers. Previously, government organizations in Kenya such as the Agricultural Development Cooperation (ADC), put much effort into production of certified seeds for farmers in the country. ADC potato seed production was however discontinued in the 1990's making it difficult for most farmers to obtain certified seed potato. Since then, much effort has been put into the establishment, expansion and development of seed potato production through farmer-based schemes (Anon., 1998a). A farmer-based seed potato production system was initiated in 1994 in an attempt to alleviate the scarcity of high quality disease free seed tubers to small-scale farmers countrywide (Anon., 1998b). In this scheme, the National Potato Research Centre (NPRC) provides high quality foundation seed to non-governmental organizations (NGOs), large-scale commercial growers, private growers and small-scale farmers for multiplication and distribution to other farmers for ware potato production. The major constraints in the production of certified seed potatoes in such a system are the management of virus diseases and their aphid vectors. Others are Late blight caused by *Phytophthora infestans*, early blight caused by *Alternaria solani*, potato tuber moth (*Phthorimaea operculella* Zeller) and nematodes (Ngugi, 1993). The solution to these pest and disease problems would result in increased certified seed and ware potato yields per unit area and an expansion of the area under seed and ware potato production. The main concern in such a scheme is the degeneration of seeds due to a build up of viral, fungal and bacterial pathogens, including aphids and the potato tuber moth pests. Efforts to address virus diseases and aphid vectors are needed if the anticipated benefits of farmer-based seed potato production are to be realized.

In Kenya seed potato is a costly input but key to increasing ware potato production (Anon., 1998b). The formal seed potato supply has not been efficient in the delivery of significant quantities of good quality seeds. Lack of good quality seed potatoes has been a perennial problem among growers. The official seed potato scheme meets approximately 1% of the 22,500 tonnes of seed potatoes required annually (Kinyae *et. al.*, 1994). As a result of this there is a definite move towards an informal potato seed market to help bridge the gap. The majority of farmers in Kenya use their own seed tubers acquired from their previous harvests. They usually keep the small-sized tubers, which are more difficult to sell, and which are not too bulky to handle during storage and planting. Occasionally, farmers fall short of planting material due to poor harvest or storage problems. In these cases, seed potatoes are obtained from neighbouring farms or purchased from the local markets oblivious of the possible latent infection status of

these tubers (Kinyae *et. al.*, 1994, Barton *et. al.*, 1997). Only a small fraction of the potato growers buy certified seed. Reasons for this have been cited as the high cost and scarcity of seed tubers, lack of an established seed potato market and in many cases, lack of know-how (Barton *et. al.*, 1997). The farmer-based seed production scheme is an attempt to alleviate the scarcity of good quality seed tubers to the small-scale farmers. Seed production at farm level seems currently inevitable. It is therefore important to understand how farmers handle their own seed production against the major pests and diseases, which cause seed degeneration and serious yield loss. Thereafter, ways should be worked out to improve on the control of these pests and diseases and increase yields from their potato crop. Thus, there is need for development of strategies that can enable farmers to produce virus free seeds.

Among the diseases, those caused by viruses are the least understood and the most difficult to control (Salazar, 1996). Viruses can often be hard to identify and characterize. Viral diseases include potato leaf roll luteovirus (PLRV) and Mosaic viruses, notably potato virus X potexvirus (PVX) and Potato Y potyrirus (PVY). Potato virus diseases are well known in industrialised countries where large amounts of money is invested in their control through the production of virus free seed and the development of resistant cultivars (Salazar, 1996). In developing countries however, only a few programmes recognise the importance of virus diseases and methods to control them are usually the same expensive methods used in the developed countries. This often leads to increased seed production costs placing the price of seed beyond the reach of poor farmers (Salazar, 1996). Potato viruses are disseminated in several ways. These include dissemination by infected tubers as for PLRV, PVY and PVX, through contact with infected plants or contaminated tools as for PVX and by insects which disseminate most viruses, examples of which include PLRV, PVX, PVY and PVS (Raman, 1985).

Insect pests of Potatoes are particularly destructive in all regions. Insect attack is usually of primary importance in hot dry climates. In Kenya, seventy species of insects have been reported on potato; 52 of them were pests and 17 were predators of those pests (Nderitu, 1991). The most common pests are aphids and the Potato tuber moth. As aphids are the main vectors of potato viruses, their control is very important in potato seed production. Among aphids, the most important vectors are green peach aphid (*Myzus persicae),* Potato aphid (*Macrosiphum euphorbiae),* glasshouse aphid (*Aulacorthum solani)* and Cotton aphid (*Aphis gossypii,* Glover). These aphids cause more damage by transmitting viruses than by feeding on the plants. The most important aphid vector is *Myzus persicae* (Raman, 1985). In Kenya, Robertson (1975)

recorded the entire four aphid species named above in different potato growing areas. Nderitu and Mueke (1986) also observed the same aphid species on eight potato cultivars. In general, the use of healthy seed and crop rotation are the most common control measures for the potato virus diseases in various parts of the world. Further work done in Kenya has also indicated the presence of some promising potato clones and cultivars, tolerant to the potato leaf roll virus (Were *et. al.*, 1996).

Some viruses, such as the PLRV cause yield losses of up to 90% in highly susceptible cultivars. Potato virus X and PVY alone or together interact with PLRV and may significantly decrease tolerance to PLRV. The three Potato viruses (X, Y and leaf roll virus) are distributed worldwide and constitute an important yield constraint. Crop degeneration caused by these viruses necessitates constant renewal of potato seed by the farmers. This is however difficult in most developing countries including Kenya because of the economic difficulties and limitations to an efficient and sufficient production of healthy seed. Economic returns of the crop, viral ecology, and the viruses themselves are different in different parts of the developed and the developing world. It is necessary to survey species of aphids and viruses in seed potato production areas in Kenya. Knowledge of aphid species on the potato fields and the proportion of those known to be vectors of virus diseases is needed for development of management strategies that will minimize virus spread. The survey would also enable us know the level of virus diseases infection in seed potato tubers produced by farmers. This would enable the production of recommendations for control strategies of viruses and aphids in different production areas and identification of research gaps needed in addressing viruses and aphids in this informal seed potato production system.

Due to the economic difficulties or the limitations in obtaining certified seed, most farmers resort to selecting seed from the previous year's crop, whose yield and quality may have been affected by virus diseases. Aphids, vectors of the virus diseases in potatoes, spread the disease further if not properly controlled. A monitoring system for aphids and viruses that is low cost, not time consuming and acceptable to the seed potato farmers needs to be developed using a participatory approach. The effect of potato aphids and viruses on yield, quality and economics of pest control in seed production areas need to be investigated. This study therefore, sought to determine the occurrence of potato viruses in farmers fields and their effect on yield and seed quality and its relationship to aphid transmission with the aim of encouraging proper preventive measures of virus infection through use of certified seed and control of aphid vectors.

1.3 OBJECTIVES

The overall objective of this study was to determine the occurrence of potato viruses, relationship to aphid vector population and effect of these virus diseases on yield and seed quality of different potato varieties.

The specific objectives were:

1. To survey for aphids and virus diseases incidence and their management practices in different Agro-ecological zones in Kenya.
2. To monitor and determine the virus disease incidence and aphid infestation in the farmers' seed potato crop under different management practices.
3. To assess the effect of virus infection and aphid infestation on yields of seed potato.

CHAPTER TWO

LITERATURE REVIEW

2.1 POTATO VIRUSES

Among viral diseases in the potato crop, the potato leaf roll virus (PLRV) and potato virus Y (PVY) are considered the main causes of potato seed degeneration (Salazar, 1996). Other important viruses are potato virus X (PVX) and potato virus S (PVS). All these Potato viruses have however not been adequately studied in Kenya.

2.1.1 Potato Leaf roll Virus

Potato leaf roll virus (PLRV) is the most economically important potato virus causing large crop losses in developing countries. The virus occurs in all countries where potatoes are grown and reduces yield as well as quality of tubers and losses may reach 90% (Harrison, 1984). This virus was first described by Quenjer *et. al.* (1916) and is called Potato phloem necrosis virus (Quenjer, 1913).

The main symptom is rolling of potato leaves and stiff upright habit of the plants. The virus has a narrow host range and hosts are mainly from the family Solanaceae, but some non-solanaceous plants such as *Amaranthus caudatus, Physalis floridana* and *Datura stramonium* are susceptible (Natti, *et. al.*, 1953). Severity of symptoms produced by this virus in *Solanum tuberosum* depends on the variety and the environment. Plants infected in the first growing season from clean seed show symptoms called 'primary symptoms' that begin on the apical leaves with rolling, erect growth and paleness. Rolling may remain restricted to the leaf base in certain varieties and progress to older leaves as disease progresses, (Jayasinghe, 1988). Plants grown from the infected seed tubers show secondary symptoms, which include reduced, and erect growth and severe rolling of lower leaves which become rigid, leathery in texture with a paper like sound when crushed. Young leaves are pale with less severe rolling than the primary symptoms (Jayasinghe, 1988).

PLRV is naturally transmitted through seed tubers and aphid vectors. It is not sap transmissible but is transmitted by about 10 species of aphids in persistent manner (Kennedy *et. al.*, 1962). PLRV is not transmitted through true potato seed (TPS) nor mechanically, thus there is no danger of contamination through tools or contact between plants (Jayasinghe, 1988). *Myzus*

persicae seems to be the most efficient vector. All instars can acquire and transmit the virus but nymphs transmit more efficiently than adults. Acquisition and inoculation feeding period of 1 day is necessary to obtain high levels of infection but aphid can acquire the virus after feeding for at least 20-30 minutes. There is a latent period of several hours, normally longer than half a day, then the aphid becomes infective and the virus infection persists throughout the aphid's life (Jayasinghe, 1988). Multiplication of the virus in the aphid has been reported (Stegwee and Ponsen, 1958).

Winged aphids blown by wind transmit the virus over long distances, while wingless aphids disseminate the disease from plant to plant (Jayasinghe, 1988). Aphids also transmit PLRV during storage especially when tubers sprout. Research at CIP has shown that stored tubers can become completely infected (Jayasinghe, 1988). Dissemination of PLRV is directly related to aphid behaviour whose populations are high in the tropics but efficiency of transmission reduces above 26°C (Jayasinghe, 1988). Traditional serological techniques such as micro precipitation, latex test and gel-diffusion cannot be used for PLRV detection probably because of low concentration in the infected plants. Enzyme- linked immunosorbent assay (ELISA) is a sensitive serological method for PLRV detection.

2.1.2 Potato Virus Y

Potato virus Y (PVY) is a major virus of potato probably only second to PLRV. It spreads very easily from plant to plant and can greatly decrease yield. Some strains can cause yield losses of 10 to 100% in potato (de Bokx and Huttinga, 1981). Combined with other potato viruses such as potato A Potyvirus, potato X Potexvirus and Potato S Carlavirus, it can be particularly damaging, sometimes destroying the entire crop.

The virus (PVY) was first described by Smith (1931) and is also called potato acripetal necrosis virus, Tobacco vein-banding virus, Tobacco veinal necrosis virus, Solanum virus 2 and Marmor upsilon. It is a virus that consists of flexuous helically constructed particles 730 X 11nm. The virus has a thermal inactivation point of 55-60 ^{0}C, a dilution end point of 10^{-3} to 10^{-4} and longevity in vitro is 48- 72 hours. The particle structure has a pitch of 3.3 nm (Varma *et. al.*, 1968).

The main symptom caused by the virus in potato is leaf-drop streak (leaves either fall from the plant or remain suspended, often giving a bare stem with leaves at the tip). Mild to severe mosaic

or vein necrosis of underside of leaflets occur in the first year of infection called stipple streak (Beemster and Rozendaal 1972). Primary symptoms are usually present following storage. However, secondary infection may produce symptoms on lifting (Beczner *et. al.*, 1984; Van den Hauvel *et. al.*, 1994). The virus is distributed worldwide and is reported to infect at least 60 plant species mostly in the Solanaceae family, but also infects members of the chenopodiaceae and leguminosae (Thornberry, 1966). *Datura stramonium* is immune to infection by all the tested strains of the potato virus Y. Weeds of Solanum Spp may be important virus reservoirs in the tropical and subtropical areas (Edwardson, 1974). Such include *S. atropurpureum* (Chagas *et. al.*, 1977) and *S. nigrum* in South America (Marchoux *et al*, 1976).

PVY is transmitted in a non-persistent manner by several aphid species, which vary in their efficiency of transmission (Kennedy *et. al.*, 1962; Sigvald, 1984). *Myzus persicae* is probably the most important and efficient vector as most studies have shown. Others are *Myzus ornatus, Macrosiphum eupharbiae, Aphis gossypii, Aphis nasturtii and Phorodon humuli.* Young upper leaves are better sources of virus for aphids (Bagnall and Bradley, 1958). Adult or later instar apterous aphids have usually been used in transmission experiments and pre-acquisition starvation period of 2 to 7 hours aids transmission. The optimum acquisition feeding period is from 30 seconds to 5 minutes. A period of 30 to 60 seconds to 24 hours is satisfactory for inoculation (Bradley 1953, Easton *et. al.*, 1958). Incidence in seed tubers can be very high in the absence of certification or tolerant varieties. However, PVY has not been reported in true potato seed though a virus in the PVY group was detected in seeds of guar (*Cyamopsis tetragonoloba,* (Hansan and Lesemann, 1978).

Serological tests such as the enzyme linked immunosorbent assay (ELISA) are available for the detection of PVY in leaf tissue from all hosts. Monoclonal antibodies are available for the differentiation of different strains of the virus, but difficulty occurs when trying to detect PVY in dormant tubers, particularly following storage (de Bokx and Cuperus, 1987). PVY can however, be detected if dormancy is broken artificially using Rindite or Gibberellic acid, and the resultant shoots tested using ELISA (Vetten *et. al.*, 1983). Progress is also being made in the use of molecular tests such as PCR for the detection of PVY in tubers (Barker *et. al.*, 1993).

2.1.3 Potato Virus X

Potato virus X (PVX) was for long considered to be of little or no importance and has even been described as healthy potato virus (Salazar, 1996) as the virus induces only inconspicuous or

symptomless infection in many potato cultivars. However, even mild strains of the virus are now known to reduce yield of the infected plants by upto 15% mainly because infected plants produce few smaller tubers (Munro, 1961). The extent of yield reduction by mild strains in field crops is closely correlated with the incidence, 100% incidence resulting in losses of 10-15% and lower virus incidence in less loss (Beukema and Van der Zaag, 1979). By contrast, necrotic strains of the virus can cause yield losses of over 50% in some cultivars. Yield losses are even bigger when the virus occurs in complex with other potato viruses, especially the potato virus Y (Smith, 1931) the replication of which is apparently stimulated by PVX (Stouffer and Ross, 1961). There is also some evidence that the PVX infected potato plants are more susceptible to infection by *Phytophthora infestans* (Pietkiewicz, 1974).

The causal agent, potato X potexvirus was first described in 1931 (Smith, 1931). The group was initially called potato virus X group and later renamed the Potexvirus group by Harrison *et. al.*, (1971). Potato virus X is also called potato X potexvirus, potato latent virus, potato mild mosaic virus, potato virus B and potato virus D. Some common names of the virus disease are, potato interveinal mosaic and potato top necrosis. The virus has flexuous filamentous particles mostly measuring 515 X 12nm, with a sedimentation coefficient of 118 S and isoelectric point of PH 5.5, a particle specific volume of $0.73cm^3/g$ and an extinction coefficient of 2.97 (Koenig and Lesemann, 1989).

The main disease caused by the virus in potato is potato interveinal mosaic and potato top necrosis whose symptoms could be, severe mosaic and leaf crinkling or acute tip necrosis usually followed by plant death by some strains as in some potato cultivars like King Edward and Aran crest. However, many strains of PVX induce only inconspicuous interveinal chlorosis in some leaves of most potato cultivars and almost symptomless infection in those of others.

PVX is easily transmitted by contact between infected and healthy plants and also by farm machinery presumably because it is very stable in vitro (Smith, 1933; Loughnane and Murphy, 1938; Roberts, 1948; Manzer and Merriam, 1961; de Bokx, 1972). It is also transmitted from infected to healthy sprouted tubers stored in the same bag (Bawden *et. al.*, 1948) and in the field on contaminated equipment (Winther-Nielson, 1972) and animals such as rabbits and dogs through contact from an infected to a healthy plant (Todd, 1958). It is also reported to be mechanically transmitted by grasshoppers *Melanopus differentialis and Tettigonia viridissima* (Walters, 1952; Schmutterer, 1959) on contaminated mouthparts. There is an unconfirmed report

that the virus is also transmissible by Zoospores of the fungus *Synchytrium endobioticum* (Nienhaus and Stille, 1965). Soilborne transmission of PVX has also been recorded (Roberts, 1946; Salazar, 1996). The virus infects potato plants systemically and is therefore disseminated by plants grown from infected vegetatively produced propagules and tubers from infected plants (Bawden *et. al.*, 1948; de Bokx, 1972); which are primary sources of infection especially if they occur as volunteers (Wright and Bishop, 1981). There is no evidence of seedborne transmission of PVX. The detection limit of PVX in potato leaves and tubers using monoclonal antibodies in DAS-ELISA is 10-20 ng/ml of Sap (Sober *et. al.*, 1988). PCR is also an established method of detection and identification of PVX.

2.1.4 Potato Virus S

Potato virus 'S' is carried by many cultivated potato varieties and is found world wide in these potato varieties where it decreases yield of potato tubers by up to 20% (Wright *et. al.*, 1977; Wenzl, 1980). However, it has a narrow host range with susceptible plant species belonging mainly to the Solanaceae and Chenopodiaceae families. The causal agent (PVS) was described first by de Bruyn and Rozendaal (1952). It is a virus with straight to slightly curved filamentous particles of 650 X 12 nm modal length and width respectively (Wetter and Brandes, 1956; De Bokx, 1970). For its stability in sap, the virus has thermal inactivation point of 55-60°C dilution end-point of 10^{-2} to 10^{-3} and infectivity is retained at 20°C for 3 to 4 days.

The disease caused by this virus shows few or no symptoms. Infected potato leaves may show slight chlorosis, roughness of the surface and undulation of the margin. There is also leaf bronzing in very sensitive cultivars infected with virulent isolates (Beemster and de Bokx, 1987). The virus is sap transmissible to a limited range of plant species while some isolates of the virus are aphid transmissible. Isolates may differ in their transmissibility by *Myzus persicae.* An isolate from the US could not be transmitted under conditions in which the related potato virus M was transmitted (Welter and Volk, 1960). Some other isolates were transmitted by *Myzus persicae* (Bode and Weidmann, 1971). Some isolates are therefore transmissible in a non-persistent manner by aphids (*Aphis fabae, A. nasturlii, Myzus persicae* and *Rhopalosiphon padi)* but other isolates are not aphid transmissible (Wetter and Volk, 1960; Bode and Weidmann, 1971; Mackinnon, 1974; Weidmann, 1986). The virus is also sufficiently infectious to be transmitted mechanically from infected to healthy field-grown plants (Khalil and Shalla, 1982; Franc and Banttari, 1984; Salazar, 1996). The virus is not seed borne or seed transmitted (Edwardson and Christie, 1997). Monoclonal antibodies have been produced to PVS/A, which

allow it to be identified specifically by ELISA (Cerovska and Filigarova, 1995). PCR can also be used for rapid identification of the virus (Badge *et. al.*, 1996).

2.2 APHID VECTORS

2.2.1 Aphid species on Potatoes

Aphids are the most economically important insect pests on Potatoes worldwide. They are primarily important as vectors of virus diseases but can also cause direct losses through feeding on the potato plant when their populations are high. Most aphid vectors of potato viruses belong to the family Aphididae. Among these aphids, the most important vectors are green peach aphid (*Myzus persicae),* Potato aphid (*Macrosiphum euphorbiae),* glasshouse aphid (*Aulacorthum solani)* and Cotton aphid (*Aphis gossypii,* Glover*).* These aphids cause more damage by transmitting viruses than by feeding on the plants. The most important aphid vector is *Myzus persicae* (Raman, 1985).

2.2.2 Transmission of Potato Viruses by Aphids

The most important mode of transmission of potato viruses is by insect vectors primarily aphids (CIP, 1996). Robertson (1975) found all the four aphid species, *Myzus persicae, Macrosiphum euphorbiae, Aulacorthum solani* and *Aphis gossypii* colonising different cultivars of potato in Kenya. Among them, *A. gossypii* was the most predominant species. Similar results were reported by Nderitu and Mueke (1986), who also found heavy infestations by *M euphorbiae* and to a less extent by *M. persicae.* In other parts of the world, *M. persicae* has been reported as the most important aphid vector (Raman, 1985). In the field, Potato cultivars display different levels of aphid infestation (Tayler, 1962; Nderitu and Mueke, 1986; Were *et. al.*, 1996). Varying levels of resistance to aphid infestation have also been reported on wild tuber bearing *Solanum* species (Radcliffe and Laner, 1970, 1971). Sams *et. al.* (1976) identified green peach aphid resistance in *Solanum* progenies, while Mndolwa *et. al.* (1984) observed greater resistance in *Solanum tuberosum* gp. *andigena* and hybrids than in gp. *tuberosum* cultivars. Nderitu and Mueke (1988) also reported some resistance in a local cultivar (Roslin Tana) in Kenya. The two observed that three potato varieties, (Annet, Kerr's Pink and Desiree) were most susceptible to aphid infestation while the variety, Roslin Tana, was identified as comparatively resistant to aphid infestation.

These aphids cause more damage by transmitting viruses than by feeding on the plants (Raman, 1985). *Myzus persicae* is the most widely distributed potato aphid and the most important vector of potato viruses. It usually feeds on the lower parts of the potato plant (CIP, 1996, Nderitu and Mueke 1986). *M. persicae* is the main aphid vector followed by *A. gossypii* in spreading both PVY and PLRV. (Pushkarnath, 1976; Khurana, 2000). In Kenya, *M euphorbiae* is mainly found at the tip of the shoots (Nderitu and Mueke, 1986).

Aphids transmit potato viruses in non-persistent or persistent manner (Raman, 1985). In non-persistent transmission, aphids may acquire viruses during brief periods of probing or feeding on the epidermal tissues of the infected plants. It may take only a few seconds for the mouthparts to become contaminated, and then the aphids can transmit viruses immediately to other plants (Raman, 1985). Aphids remain infective (viruliferous) for a short period, usually not more than two hours and viruses can only be carried over short periods and distances. Except for the potato leafroll virus, all aphid-borne potato viruses are non-persistently transmitted. These include potato virus Y, A, M (PVY, PVA, PVM) and some strains of potato virus S (PVS). Of this group, PVY is the most important virus (CIP, 1996).

In persistent transmission, viruses transmitted by this method are located in the Phloem tissue of plants. To acquire them, an aphid must feed on the phloem, and not just probe on the leaf surface. This may take 20 to 30 minutes. The virus enters the body of the aphid and during an additional latency or incubation period lasting several hours, the aphid usually remains non-viruliferous. Then the virus persists throughout the aphid's life and can be carried over long distances. The best known persistently transmitted potato virus is the potato leafroll virus (PLRV), which is also the most important potato virus (CIP, 1996).

2.2.3 Control of Aphids and Virus Spread

Because virus spread is related to aphid populations, seed production areas should be selected on the basis of aphid population studies (Raman, 1985). In Kenya, Were *et. al.,* (1996) found that the potato aphid, *Macrosiphum euphorbiae,* multiplied more rapidly under green house conditions than the green peach aphid, *Myzus persicae,* with *M. euphorbiae* colonising mostly the upper leaves followed by the middle and then the lower bottom parts. On the other hand, *M. persicae* colonised mostly the lower leaves followed by the middle then the upper leaves. He recorded that generally, the population of aphids varied with age of the leaf with *M. persicae* colonising the older leaves while *M. euphorbiae* was on young leaves. Nderitu and Mueke

(1986) had also found that the two aphid species *M. persicae* and *M. euphorbiae*'s abundance at particular level of potato plant differed with the season. However, during both long rain and short rain seasons, bottom leaves maintained the highest population, while the upper leaves maintained the lowest populations but the variation was less in the short rains.

Aphid populations are generally low in areas with low temperature, abundant rainfall, and high wind velocity (Raman, 1985). To reduce dissemination of viruses through viruliferous aphids within a potato growing area, seed potato fields should therefore be located upwind from the commercial potato fields and alternative host crops or completely separated from the commercial potato production. After a viruliferous aphid has fed on foliage, a virus needs sometime to reach the tubers. Good grade seed potatoes should therefore be harvested not later than 8 to 10 days after population study has revealed a critical aphid build-up, which is sufficient time to avoid virus infections reaching the tubers (Raman, 1985).

Chemical control by use of aphicides depends on the type of virus transmission involved. In non-persistent transmission of viruses, such as PVY, aphids transmit the viruses faster than common aphicides can react to kill the vector hence aphicides can only slightly reduce non-persistent virus transmission but cannot prevent it. In persistent transmission of viruses such as PLRV, the incubation period is long enough to allow aphicides to control vectors and can therefore greatly reduce PLRV spread within a field though they can not control infections from outside by migrating aphids (Raman, 1985). Chemical insecticides such as cypermethrin, pirimicab, carbofuran, dimethoate and metasystox have been found effective in controlling aphids in potatoes (Nderitu and Mueke, 1986; Woodford, 1992; Woodford and Mann, 1992;Nagal *et. al.*, 1994;Rieckman, 1995,Boiteau *et. al.*, 1997; Singh and Narwaria, 1997; Zkukoova and Timofeer, 1998; Rongai *et. al.*, 1998). However over reliance on insecticide use has caused insecticide resistance (Harrington *et. al.*, 1988,1989; Rongai *et. al.*, 1998; Duvauchelle and Dubois, 1997).

Other measures recommended in order to produce virus free seeds include cultural practices such as growing of seed potatoes during periods of zero tolerance or reduced aphid population. Alternative host plants of aphids such as carrots, cotton, peppers, egg plants and tobacco should not be grown in close proximity of the Potato seed crop. Diseased plants and foliage should be removed as the crop approaches maturity to avoid infestation by aphids and infection by potato viruses (Ioanou, 1988;Difonnzo *et. al.*, 1996). Evaluations of potato genotypes against aphids

damage have showed some differences in susceptibility (Khattab *et. al.*, 1995; Difonzo *et. al.*, 1995; Parah *et. al.*, 1996). Some potato genotypes have some tolerance to virus diseases (Difonzo *et. al.*, 1995). The spread of potato leaf roll virus and potato virus Y, which are aphid-borne could be decreased by use of resistant genotypes to the virus. Potato crops could be monitored for the presence of viruses just after emergence and at 45 days after emergence (Rongai and Cerato, 1997). Infection rates greater than 3% just after emergence indicate that there is a serious problem of viruses in the seed potato. The virus spreads rapidly to all plants after infestation by aphids when there is a point source of PLRV in the plots (Thomas *et. al.*, 1997).

Parasites and predators attack aphids on potatoes and reduce their numbers (Ray, 1989; Kish *et. al.*, 1994; Stotz *et. al.*, 1997; Tae and Long, 1998). The natural enemies identified are *Aphidius nigripes, Coccinella septempuncta* and *Menochilus sexmaculatus* (*Cheilomenes sexmaculata*). The effect of predation by ladybird beetles on the population of aphids on potatoes has been evaluated (Dogan *et. al.*, 1996; Lagnaoui and Radcliffe, 1998; Birch *et. al.*, 1999).

CHAPTER THREE

SURVEY OF APHIDS AND VIRUSES IN FARMERS SEED POTATO FIELDS IN CENTRAL AND RIFT VALLEY PROVINCES IN KENYA

3.1 INTRODUCTION

The problem of lack of adequate and affordable certified seeds within the reach of small scale farmers has led to an increased effort towards the improvement, expansion and development of seed potato production through farmer based schemes (Anon., 1998a). The farmer-based seed production scheme is an attempt to alleviate the scarcity of good quality seed tubers to the small-scale farmers. However, this production system is handicapped by the farmers' inability to manage viruses and aphids, which are the key constraints to production of certified seeds. Other constraints include late blight by *Phytophthora infestans* (Mont)), early blight by *Alternaria solani*, potato tuber moth (*Phthoremae operculella*, Zeller) and nematodes (Ngugi, 1993). Virus diseases of potato in most potato production systems in developing countries are usually given less prominence because they do not cause immediate visible physical damage unlike late blight and bacterial wilt. Yet viral infection in potato is known to reduce potato yield through seed degeneration (Beukema and Van der Zaag, 1990). Virus infections in seed tubers may not only affect yield but also the quality of ware potato (Omer and El-Hassan, 1992). Seed production at farm level however seems currently inevitable. It is therefore important to understand how farmers handle their own seed production against the major pests and diseases, which cause seed degeneration and serious yield loss. In this regard, a survey was conducted to assess the occurrence of four major potato viruses (PLRV, PVY, PVX and PVS) and their main aphid vectors in different agro ecological zones (AEZs) in Kenya. This field survey was conducted with the aim of collecting information on the Potato insect pests particularly aphids and diseases particularly virus diseases and their management practices in seed potato farms, in different Agro-ecological zones. The survey was necessary to determine the incidence and identity of major virus diseases and aphids in farmer-based seed potato crop in these areas.

3.2 MATERIALS AND METHODS

3.2.1 Site selection

A formal survey was conducted in three major farmer based seed–potato production areas in different agro-ecological zones to assess the major potato pests and diseases with emphasis on

the potato virus diseases and their aphid vectors. The survey was done in Tigoni area of Kiambu district (Low AEZs, around 2,100 metres above sea level (m.a.s.l), Njabini area of Nyandarua district (Medium AEZs, areas around 2,500 m.a.s.l), both in Central Province and in Molo area of Nakuru district (Higher AEZs, areas around 2,800 m.a.s.l) in the Rift Valley Province, Kenya. These are important potato growing areas in the country, which also host the National Potato Research Centre (NPRC) in Tigoni, and Potato Research Sub-centres at Njabini (in Nyandarua) and Marindas (in Molo area). Twenty farmers were selected from each of the three areas making a total of sixty farmers for the survey. The farmers were selected with the guidance of potato research officers in the respective areas with emphasis on farm-based seed potato growers. A potato field of about quarter a hectare was surveyed in each farm. The surveyed areas; Tigoni in Kiambu District is in Agro-ecological zones, upper midland 1,2 and 3 (UM_3, UM_2, UM_1) and lower highland 1 (LH_1) with a rainfall of 550 to 740mm; Njabini in Nyandarua district in Agro-ecological zones, upper highland 1 and 2 (UH_1, UH_2) and Molo area, in Nakuru district in similar agro-ecological zones, UH1 and UH_2 with a rainfall of 480-940mm (Appendix 1) (Jaetzold and Schimdt, 1983).

3.2.2 Survey of Viruses

The virus disease incidence was estimated using the method defined by James (1974). The potato field (about quarter of a hectare in each farm) was divided into 5 roughly equal portions. In each portion, 20 plants were scored for virus disease symptoms, making a total of 100 plants in each field. The number of plants observed with virus symptoms (Plate1) were recorded and then expressed as a proportion of the total number of plants observed (100). This gave the percentage virus disease incidence in that farm.

Plate 1: Virus diseased potato plant at the centre

Samples of the symptomatic leaves were collected from each farm. Three leaves showing virus symptoms were collected from each plant sample selected. 10 samples were picked from each farm and these were put in a cool box for transportation to the laboratory where they were kept in a refrigerator at 4 ^{0} C. At the end of the 3 days of survey for each area, the leaf samples were processed for serological assay to test for the presence of four major potato viruses, namely potato leaf roll virus (PLRV), Potato virus Y (PVY), Potato virus X (PVX) and potato virus S (PVS). Direct Double Antibody Sandwich-Enzyme Linked Immunosorbent Assay (DAS – ELISA) Method as described by Clark and Adams (1977) was used (Appendix 2). A total of 129 samples were analyzed with at least 2 samples from each farm (43 per area). Each sample was put in two microtitre wells of an Elisa plate as duplicates. Two (A and B) samples were analyzed from each farm. Therefore, 2 microtitre wells represented a sample and 4 wells represented a farm. Two control wells were included in each assay for comparative purposes. Only the buffer solution was put in the control wells but no extract from the plant leaf samples. Virus infected samples were assessed visually from yellow colour development in each micro-titre well. The ELISA-plates were then put through an ELISA reader and virus reactivity data per well recorded in a printout. This was later analyzed to determine the positive samples for each of these four major potato viruses. Positive samples from the readings of the ELISA-reader were those where the mean of their two duplicate wells was greater than the mean of the 2 healthy control wells multiplied by two.

3.2.3 Survey of Aphids

Thirty plants were selected at random from each farm in an area of about quarter of a hectare. From each plant, a total of 3 compound leaves were picked from the top, middle and bottom positions, making a total of 90 leaves per farm. Leaves from each plant position were put in a separate sampling bag. Thus all 30 top leaves from a farm were put in one bag, middle leaves in a separate bag and all bottom leaves in another bag. These were also put in a cool box and later observed under a stereo dissecting microscope at the University's laboratory. Population counts were done separately in the laboratory for the aphids (Plate 2) collected from each farm and at each leaf position and these were recorded. The aphids counted were preserved in 60% alcohol and then later identified to species level at the university's entomology laboratory using the dissecting microscope and separated into the different species. The species were identified as described by Eastop, 1953 (Appendix 3). The data was then subjected to analysis of variance using the SPSS computer program.

Plate 2: An aphid colony on a potato plant

3.2.4 Formal questionnaire

The survey involved administering a questionnaire (Appendix 4) to each farmer visited. A total of 60 farmers, with an equal number chosen from each of the 3 districts (20 farmers each), were visited and interviewed on the major pests and diseases in their farms and how they manage them. The information gathered in the questionnaire included the location and size of the farm, area under potatoes, agro ecological zone and potato varieties grown in the farm. Others were source of farmer's seed, major pests and diseases on the potato crop in the farm and how the farmer controls them. Socio-economic factors like the age of the farmer, experience in farming and who was the decision maker on the farm were also recorded. This data was then analysed using the Statistical Package for Social Scientists (SPSS) computer programme.

3.3 RESULTS

3.3.1 General Potato pests and diseases in the survey area

Over 20 pests and diseases were found associated in varying levels with the potato crop in the surveyed area. A total of 15 pests and 6 diseases were observed and recorded in the crop during the survey period (Table 3.1). Pests observed included insect pests (which were the main group of pests), vertebrate pests and nematodes. The main insect pests identified, in order of occurrence were various species of aphids (found in all the farms in the survey - 100%), potato tuber moth (*Phthorimaea operculella*), in 67% of the farms, leafhoppers (*Erythroneura* sp.) in 27% of the farms, and cutworms (*Agrotis* sp.) in 25% of the farms. Others included whiteflies (*Bemisia*

tabaci) 23%, ants (*Macrotermes sp.*) 13% and Epilachna beetles (*Epilachna similis*) 12%. Other insect pests, vertebrate pests and nematodes occurred in less than 10% of the farms.

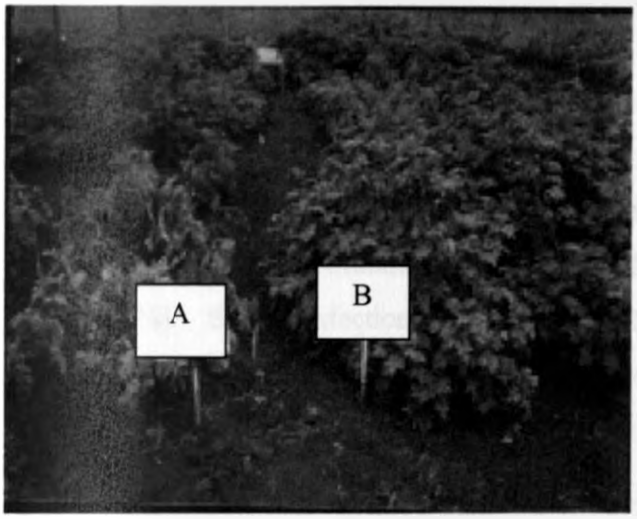
The main diseases observed were different virus diseases in all the farms (100%), Late blight by *Phytophthora infestans* (also in 100% of the farms) and bacterial wilt (in 56% of all the farms). The other diseases were found in less than 10% of the farms surveyed (Table 3.1).

Table 3.1: Major Pests and Diseases attacking the potato crop in three main potato growing areas in Kenya

		% OF FARMS WHERE PEST WAS FOUND			
	PEST/DISEASE	**TIGONI**	**NJABINI**	**MOLO**	**AVERAGE**
A	**INSECT PESTS**				
1	Aphids	100	100	100	100
2	Potato tuber moth (*Phthorimaea operculella*)	85	80	35	67
3	Leaf hoppers (*Erythroneura* sp.)	50	25	5	27
4	Cutworms (*Agrotis* sp.)	5	30	40	25
5	White flies (*Bemisia tabaci*)	55	10	5	23
6	Ants (*Macrotermes sp.*)	0	0	40	13
7	Epilachna beetles (*Epilachna similis*)	15	20	0	12
8	Caterpillars (*Helicoverpa armigera*)	5	0	25	10
9	Centipedes (*Lithobius* sp.)	5	10	5	7
10	Dusty brown beetle (*Gonocephalum simplex*)	15	0	0	5
11	Leaf miner (*Liriomyza* sp.)	10	0	0	3
B.	**VERTEBRATE PESTS**				
1	Rodents	5	0	0	2
2	Porcupines	5	0	0	2
3	Moles	5	0	0	2
C.	**NEMATODES**	5	0	0	2
D.	**DISEASES**				
1	Viruses	100	100	100	100
2	Late blight	100	100	100	100
3	Bacterial wilt	60	45	65	56
4	Rhizoctonia	5	0	10	5
5	Bacterial blight	0	5	5	3
6	Scab	0	5	0	2

3.3.2 Virus survey

The most encountered single potato viral infection was PVS, which was positive in 79.1% of all the samples analysed. This was followed by PLRV, 34.9% and the less encountered viruses were PVY - 8.5% and PVX - 7.0% (Plate 3 and Table 3.2). Viral diseases were most prevalent in the Tigoni area, Kiambu district, with an average of 47.1% of the samples being positive to the 4 viruses (with all samples, (100%) positive for the PVS infection). The prevalence in the other two areas was 25.6% in Njabini, Nyandarua district and 25% in Molo, Nakuru district. The overall average percentage of samples showing positive reaction to the 4 viruses tested in the 3 areas was 32.3% (Table 3.2).



A virus infected plot (A) and a clean plot (B)

Plant with PVY virus symptoms

Plant with PLRV virus symptoms

Plant with PVS virus symptoms

Plate 3: Virus disease symptoms observed in the field

Table 3.2: The % occurrence of Potato virus S (PVS), Potato leaf roll virus (PLRV), Potato virus Y (PVY) and Potato virus X (PVX) in Tigoni, Njabini and Molo areas

VIRUS	AREA			AVERAGE
	TIGONI	NJABINI	MOLO	
PVS +ve	100	53.5	83.7	79.1
PLVR +ve	53	41.9	9.3	34.9
PVY +ve	25.6	2.3	0	8.5
PVX +ve	9.3	4.7	7.0	7.0
Average +ve	47.1	25.6	25.0	32.6

The occurrence of these viruses singly and in different combinations in the survey areas was 100% in Tigoni, 88.4% in Molo and 76.6% in Njabini (Table 3.3). On average for the 3 areas, 88.4% of the samples reacted positively for at least one of the 4 viruses or their different combinations. One of the samples had multiple infections of all the four viruses. This sample infected by all the 4 viruses was collected from Njabini area. Infections involving 3 viruses accounted for 6.3% of all the samples. Double infections were common (27.2%) with the frequently encountered combination being that of PVS + PLRV (20.2%), then PVS + PVY / PVX (6.2%). Single infections were in about half of the samples (54.3%) involving PVS (46.5%) and PLRV (7.8%). PVY and PVX were not encountered singly. Single and double viral infections were found in all the 3 areas, while all the 8 samples (18.7%) with triple viral infections were from Tigoni.

Table 3.3: Infections (%) by PVS, PLRV, PVY and PVX for single and multiple infections of the potato leaf samples collected from Tigoni, Njabini and Molo.

Viral infection/combination	AREA			Average
	Tigoni	Njabini	Molo	
Un-infected	0	23.3	11.6	11.6
PVS alone	30.2	34.9	74.4	46.5
PLRV alone	0	20.9	2.3	7.8
PVY alone	0	0	0	0
PVX alone	0	0	0	0
PVS + PLRV only	39.5	16.3	4.7	20.2
PVS + PVY only	11.6	0	0	3.9
PVS + PVX only	0	2.3	4.7	2.3
PLRV + PVY only	0	0	0	0
PLRV + PVX only	0	0	2.3	0.8
PVY + PVX only	0	0	0	0
PVS + PLRV + PVY only	9.3	0	0	0
PVS + PLRV + PVX only	4.7	0	0	3.1
PVS + PVY + PVX only	4.7	0	0	1.6
PLRV + PVY + PVX only	0	0	0	1.6
PVX + PLRV + PVY + PVX all	0	2.3	0	0.8
Total - Infected samples (%)	100	76.7	88.4	88.4

There was a significant difference in the percentage of virused samples between the different virus types (P<0.01) but not between the sites (P=0.05).

3.3.3 Aphids survey

The aphid populations were highest in Tigoni area (average 73 per farm), followed by Njabini area (26 per farm) and lowest in Molo area (11 per farm), (Fig.3.1). The aphid numbers were highest at the bottom position of the leaves in all areas (average 18 per farm), followed by the middle position (12 per farm - average) and least at the top position (average 6 per farm). There were no significant differences in the aphid numbers between the different leaf positions at any of the 3 survey areas. However, there were significant differences in the aphid numbers between the different sites with Tigoni area having significantly higher aphid populations than the other two areas (P=0.05). The difference in aphid populations between Njabini and Molo was however not significant though Njabini had slightly higher aphid populations than Molo. There were significant differences in aphid populations between the sites but not between the leaf positions (P= 0.05) (Fig. 3.1)

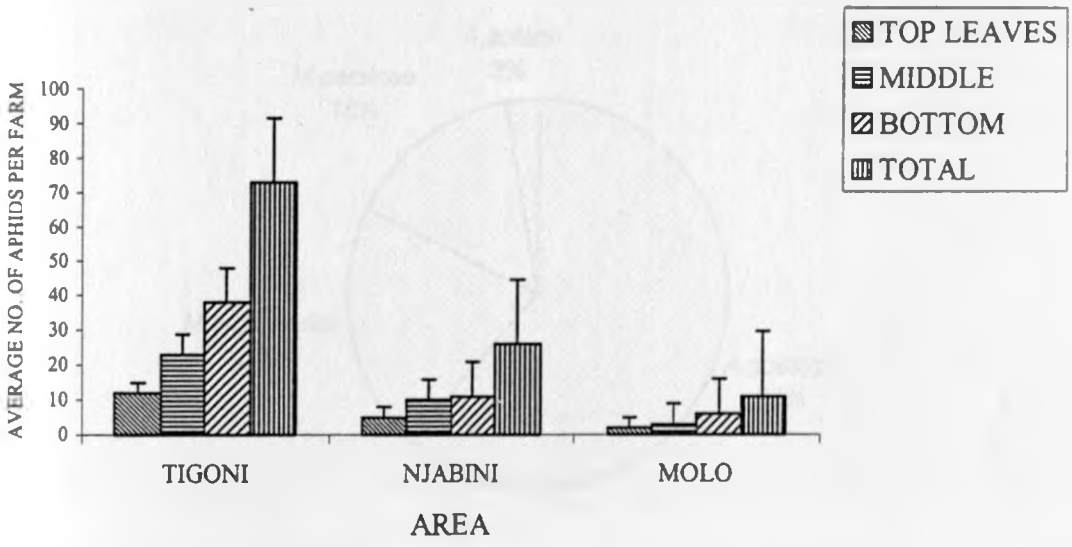


Figure 3.1: Aphid population at different leaf positions in the 3 survey areas in December 2001.

Fig.3.2 shows the graphical presentation of overall species populations at the 3 survey areas while Fig.3.3 shows the overall percent proportions of the aphid species in the 3 survey areas combined.

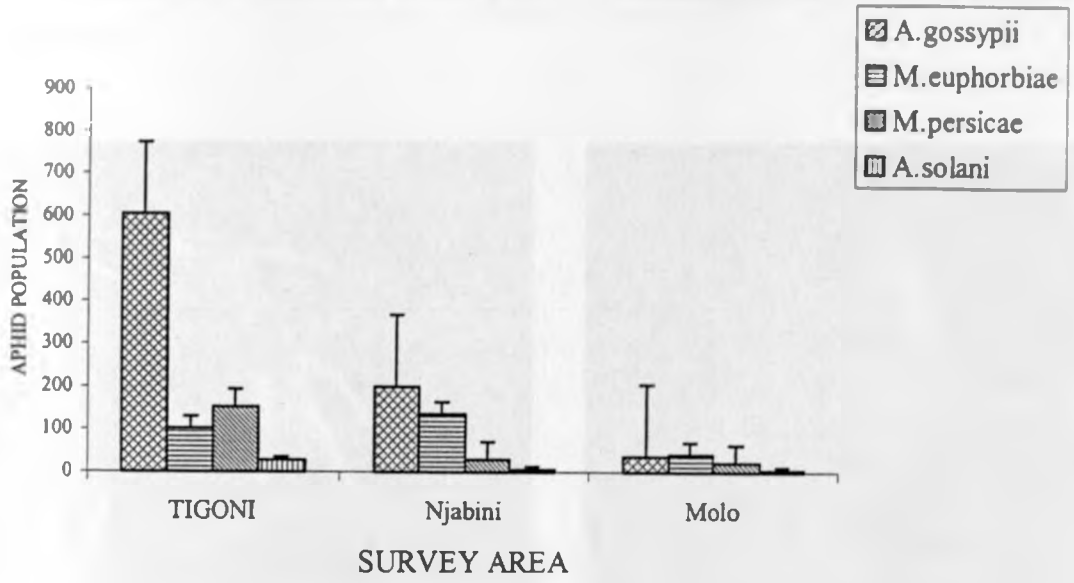


Figure 3.2: Aphid species in the 3 survey areas in December 2001.

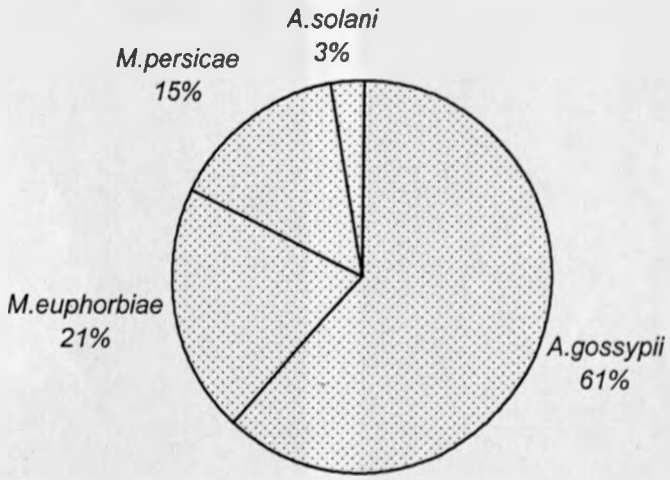


Figure 3.3: Proportions of aphid species in the 3 survey areas combined

Aphis gossypii (Plate 4) was the most prevalent aphid species accounting for 61% of all the species identified in the 3 survey areas (Fig.3.3). This was followed by *Macrosiphum euphorbiae*

aphid species was *Aulacorthum solani* (Plate 7), accounting for only 2.8% of all aphid species identified.

Plate 4: *Aphis gossypii* (Cotton aphid)

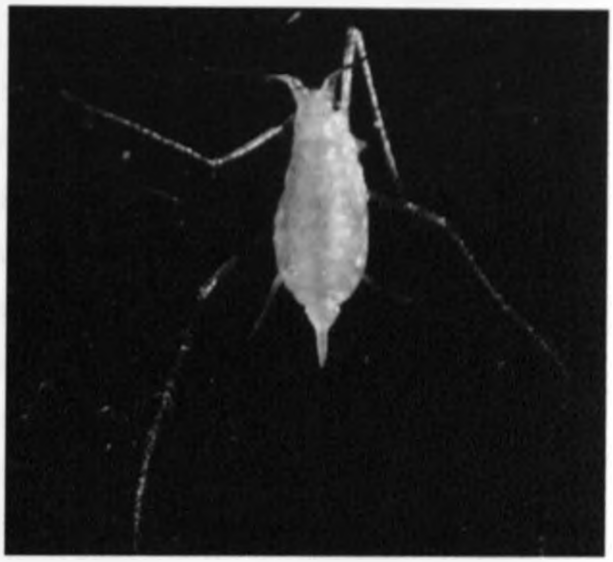


Plate 5: *Macrosiphum euphorbiae* (Potato aphid)

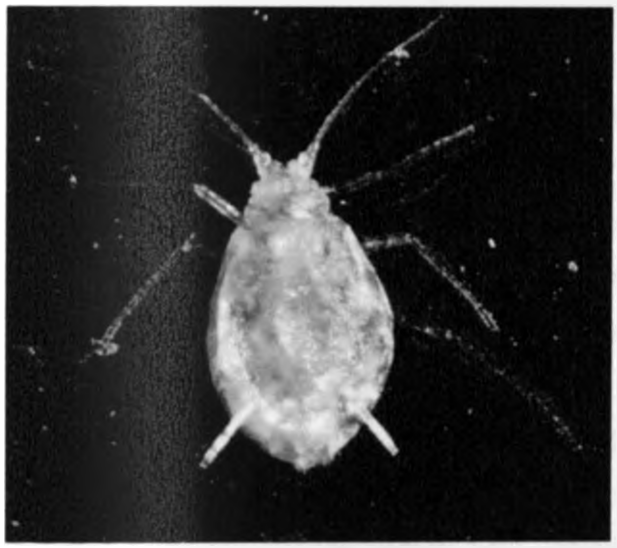


Plate 6: *Myzus persicae* (Green peach aphid)

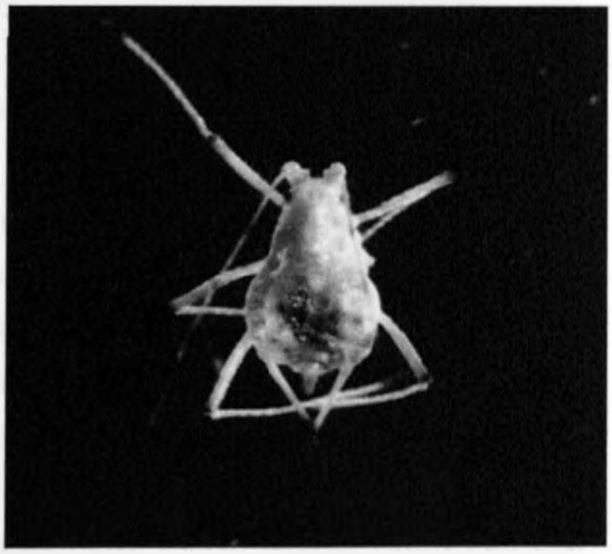


Plate 7: *Aulacorthum solani* (Glass house aphid)

There were significant differences in aphid species population counts between the different species (P=0.05). *Aphis gossypii* had significantly higher populations than the other 3 species at the Tigoni site but not in the other 2 areas (Fig. 3.2). Comparing the sites, *A. gossypii* and *Myzus persicae* had also significantly higher populations at the Tigoni area than in the other 2 areas.

The different areas in the different agro-ecological zones exhibited differences in the order of species abundance. Tigoni area had *Aphis gossypii* as the most abundant species (68.2%) followed by *Myzus persicae* (17.2%) then *M. euphorbiae* (11.5%) and lastly *A. solani* (3.2%). In the other two areas (Njabini and Molo) the order of abundance of these species changed with *M. euphorbiae* having higher populations than *M. persicae* to become the second most abundant species in Njabini area, and further increasing in proportion even more than *A. gossypii* to take the first position as the most abundant species in Molo. The distribution of the species on the plant shows that bottom positioned leaves had higher populations of the aphid species (42.5% on average) followed by middle leaves (37.4%) and then top leaves which had the lowest proportion of aphid species (20%). A. *gossypii* particularly showed preference of the lower leaves (44.8%), then middle leaves (38.1%). *M. euphorbiae* showed preference of the middle leaves in the colder higher altitude of Njabini and Molo (42.8%) while it was more abundant in the lower leaves in the warmer lower altitude of Tigoni (56.9%). *Myzus persicae* was also more abundant in the middle leaves in Tigoni (46.1%) but the populations were higher in the lower leaves (47.4%) in Molo and Njabini. However, these differences in aphid numbers between the different leaf positions were not significant (P=0.05). *A. solani* was almost absent in all the 3 areas accounting for an overall proportion of only 2.8% of all the aphids identified in the 3 areas.

3.3.4 Farmers responses on their preferences and management practices in seed potato production

The majority of farmers (70%) in all the survey areas are small-scale farmers with a total land size of 5 hectares or less. The area under potatoes was less than 1hactare for 85% of the farmers in the survey areas with 65% actually growing potatoes in an area of less than ½ a hectare. Tigoni was the variety preferred and grown by most farmers (60 %) who gave the main reason for preferring the variety as high yields (58.3% of the farmers). More than half (55%) of the farmers interviewed bought (or put a cost to) their potato seed at 10 to 20 Kenya shillings per Kg. About 80% of the farmers used uncertified seed from various sources, mostly own seed. Most of the farmers in the survey areas (80%), used chemicals for pest and disease control, mostly for control of late blight (66.7%), with the most commonly used chemicals being Ridomil (40%) and Dithane (25%). A majority of the farmers (about 60%) did not have any knowledge of virus diseases in potato. Those who could recognize the diseases said they mostly noticed them just before potato flowering (53.3%). Surprisingly, more than 66.7% of the farmers reported yields that amounted to more than the recorded national average of 4.4 tons/ha. A majority of the farmers (66.7%) weed their crop 2 times in a season and 80% practice crop rotation. Planting

time for most farmers was in the months of September to November (about 80 %) with the peak planting time being the month of October (35 %). About 70 % of the farmers do not intercrop their potatoes with other crops and those who do (30%), intercrop mainly with maize or other horticultural crops. Sixty five percent of the farmers adopted crop protection practices and the source of this knowledge was the ministry of agriculture for most farmers (55%). The major avenues for marketing the farmer's potato harvest were the local market (50%) followed by marketing to middlemen from other towns (25%). Over 90% of the farmers store their potato harvest, with 60% storing for less than 3 months, 33.3 % for more than 3 months and 6.7% did not store their potato tubers at all. The farmers were almost equally distributed between the seed farmers (51.7%) and the non-seed farmers (48.3%). Sixty five percent of the farmers were male and 35% female. About 90% of the farmers were aged between 30 and 70 years with only one farmer of all the 60 interviewed being below 30years of age and 6 farmers (10 %) over 70 years. Experience in farming for the different farmers varied almost uniformly from below 10 years to over 40years. Sixty five percent of the farmers had between 10 to 40 years farming experience, 21.7% below 10years and 13.3% above 40years experience in farming. Decision making on the farm was done mainly by the husband (65%), Wife (23.3%) and farm manager (8.3%).

There was a positive correlation between aphid populations and the presence of the two aphid–transmitted viruses, PLRV ($r = 0.255$, significant at $P=0.05$) and PVY ($r = 0.343$, significant at $P=0.01$). However, correlation between aphid numbers and the presence of the other two viruses, PVS and PVX was not significant ($P=0.05$). There was also a correlation between the visual virus incidence and the type of farmer ($r = 0.266$, significant at $P=0.05$), with non–seed farmers having higher virus incidence than seed farmers. PLRV was also more in non-seed farmers than in the seed farmers and a significant correlation was recorded ($r = 0.535$, significant at $P=0.01$). There was no significant correlation between the type of farmer (seed or non-seed) and the other 3 viruses, PVY, PVS, and PVX. The height (Altitude) of the survey area's AEZ was negatively correlated with the number of aphids collected from the area ($r = -0.548$, Significant at $P=0.01$), with fewer aphids in the higher areas than in the lower AEZ areas. The height (Altitude) of the Survey area's AEZ was also negatively correlated with the presence of PLRV ($r = -.490$, significant at $P=0.01$) and PVY ($r = -0.445$, significant at $P=0.01$). However, there was no significant correlation between the height of the area and the overall visual virus incidence recorded and also the presence of PVS and PVX ($P=0.05$).

3.4 DISCUSSION

3.4.1 General Pests and diseases

These results revealed that the potato crop is attacked by many pests and diseases. Within the short period of this survey, over 20 pests and diseases were encountered in the survey area. This suggests that, a more thorough search of pests and diseases in the potato crop over a wide area and a longer period might capture many more pests of the potato crop. This agrees with earlier work done in Kenya, where seventy species of insects were reported on potato. Fifty two of them were pests and 17 were predators of these pests (Nderitu, 1991). It is also evident from the results of this survey that, virus diseases and their aphid vectors, rank among the most widely encountered pests and diseases in the potato crop. The two were encountered in all the farms surveyed. The only other disease that was found in all the farms was late blight (*Phytophthora infestans*). This agrees with earlier work where it was reported that virus diseases, late blight, early blight (*Alternaria solani*), aphids, potato tuber moth (*Phthorimaea operculella*) and nematodes had been identified as among the major pests and diseases constraining the production of certified seed potatoes (Ngugi, 1993). This shows that more emphasis needs to be put in the study and management of virus diseases and their aphid vectors. This is necessary since, unlike the late blight disease, which was found in as many farms, the virus diseases have not received much attention yet they have been identified as a major constraint in the production of seed potato.

3.4.2 Viruses

The results of the virus study show that viruses occur in the main potato-producing areas of Kenya. The high incidence of viral diseases suggests that these diseases are a major constraint to potato production in Kenya. This high incidence of viruses in most potato fields in the three survey areas could be attributed to lack of certified and hence low use of the certified seed by the farmers. In most farmers' fields, the most common varieties grown were Tigoni and Asante which initially originated from the potato seed programme, of the National Potato Research Centre (NPRC) and Agricultural Extension services. However, most farmers had later continued to grow self-generated seeds recycled from the certified seed for several generations as is reflected by the farmers response on the source of their potato seed.

As Slack and German (1998) found, viral diseases of potatoes are particularly important because they are seed perpetuated, and there is no way to immediately clean-up currently infected potato

plants in the field. This may account for the high incidence of viruses in many potato fields at farm level and a relatively low level of virus incidence in the seed stock at the NPRC at Tigoni and the sub centres in Marindas-Molo and Njabini, where seed is regularly replenished. Virus infections in seed are mainly found in certified seed that was recycled for more than three generations. This implies that if these materials are to be maintained in a clean potato programme, they should be cleaned of viruses (Kakuhenzire *et. al.*, 2000). There was a high occurrence of all the 4 viruses in Tigoni area (47.1%) which stands at lower altitude Agro-ecological zones (LH1, UM_1, UM_2 and UM_3) compared to the other 2 areas Njabini (25.6%) and Molo (25.0%) which are both in upper altitude zones (UH_1, and UH_2). This suggests that the virus diseases are more serious in lower altitude areas than in the colder higher altitude zones.

These results compares well with similar findings in Uganda where occurrence of the same 4 viruses singly and in different combinations was found to be higher (98.3%) in Mbarara, which was at a lower altitude (1400 meters above sea level (m.a.s.l) than in Kabale (94.7%) at an altitude of 1820 m.a.s.l. (Kakuhenzire *et. al.*, 2000). Occurrence of these viruses singly and in combinations in Kenya was 100% in Tigoni, 88.4% in Molo and 76.6% in Njabini.

3.4.3 Aphids

The occurrence of aphids as the most widely distributed pest in the potato crop (100%) and also the ranking of viral diseases as the most widely distributed (100%) sharing the position only with late blight shows that there is a great risk in seed potato production in Kenya. Potato viruses are most common in the subtropics due to high aphid vector activity and lack of healthy seed affecting seed quality (Khurana, 2000). It is known that aphids cause more damage by transmitting viruses than by feeding on the plants (Raman, 1985).

In previous work (Khurana, 2000), it has found that the mild potato viruses namely PVS and PVX (which depress yields by 10-30% in infected plants) readily spread upon contact of plant foliage and roots in the field. However, the most serious viruses namely PVY and PLRV (which have the potential to reduce yields by 60-80%) are spread by aphid vectors, both from far off fields by migrant winged aphids and within the crop by viviparous apterae developing aphid colonies. It has also been found that *Myzus persicae* is the main aphid vector followed by *Aphis gossypii* in spreading both PVY and PLRV (Pushkarnath, 1976, Khurana, 2000). The occurrence of the two species *M. persicae* and *A. gossypii* among the most abundant species in the survey areas, posses a great constraint to potato production in these areas. *A. gossypii* ranked first in

abundance in the 3 areas. *Myzus persicae* ranked second after *A. gossypii* in Tigoni area which shows that this area is at the greatest risk of virus spread among the 3 areas. Njabini area also had *A. gossypii* as the most abundant with *M. persicae* ranking third putting it in second position of the risk of virus spread by the aphids. The area with the lowest risk was Molo where the most predominant species was *M. euphorbiae* with *A. gossypii* and *M. persicae* ranking second and third respectively.

The results of the aphid survey and study actually agree with the study on viruses survey in the same area where it was found that PLRV and PVY were most prevalent in Tigoni area (positive in 53% and 25.6% respectively), followed by Njabini area (41.9% and 2.3%) and least in Molo area (9.3% and 0%) respectively. These results show that viral diseases are prevalent in Kenya. The most encountered virus was PVS, which is considered mild with minimal effect on potato yields, but when the virus occurs in combination with other viruses, it can drastically affect the yields (Mih *et. al.,* 1993). The occurrence of PLRV as the second most encountered virus and the frequently encountered multiple infections of the 4 viruses posses a serious threat to potato production as the combination of even the mild viruses (PVS and PVX) with the other more serious viruses (PLRV and PVY), increases the effect of yield reduction on the potato crop.

These results also show that both the virus disease incidence and the aphid vector pressure is higher in lower altitude agro-ecological zones, such as in Tigoni ((LH_1, UM_3, UM_2 and UM_1) than in the colder higher altitude zones in Njabini and Molo (UH_1 and UH_2). Therefore, these higher altitude areas whose potential for potato production is also higher, would be best suited for seed potato production both farm-based and research-based with minimal risks of virus spread. Farmers in these areas should therefore be encouraged to engage in clean farm-based seed-potato production to supplement the serious deficit in certified seed potato production by the National Potato Seed Programme. Farm-based seed potato production in the lower altitude, Tigoni area needs to be carefully monitored for aphid populations and proper control measures undertaken. This is because this area is at a higher risk of virus spread in the potato crop due to the high vector pressure and the greater abundance of the more serious virus transmitting aphid species.

3.4.4 Management practices in seed potato production

It was evident from the responses given by the farmers that most of them (60%) have no knowledge of virus diseases in the potato crop. This, coupled with their response that the

majority of them (80%) used uncertified seed from various sources should be a course for concern on the spread of virus diseases in this farm-based seed production system. Earlier studies had also found that the majority of farmers in Kenya use their own seed tubers acquired from their previous harvests or seed purchased from the local market or their neighbours oblivious of the latent infection status of these tubers (Kinyae *et. al.*, 1994). In Kenya, seed potato is a costly input but key to increasing ware potato production (Anon., 1998b). Since most of these farmers (70%) are small scale, their resource base is limited and most cannot afford to buy certified seed frequently. Planting their own seed or seed obtained cheaply from neighbours or the local market is therefore inevitable. It is therefore necessary to train these small-scale farmers on proper management measures for virus diseases and their aphid vectors. This will ensure that farmers are aware of the effect of the virus diseases in reducing yields of their potatoes. It was clear that most farmers (80 %) use chemicals and this was mostly to control late blight. This could be attributed to the fact that the farmers are aware of the danger posed by this disease to their potato crop since the effect of late blight can be seen immediately. Therefore, if the farmers are also made aware of the serious effects of virus diseases on yields of their crop, they would be prepared to take the appropriate control measures leading to the production of better quality seed potatoes.

The positive correlation between the aphid populations and the presence of two viruses (PLRV and PVY) suggests that the aphids have played a major part in the spread of the two viruses. This agrees with earlier reports that aphids (particularly *Myzus persicae* and *Aphis gossypii*) are the main vectors in spreading both PLRV and PVY (Pushkarnath, 1976; Khurana, 2000). The correlation where the non-seed farmers had higher virus incidence than the seed farmers also shows that seed farmers at least did some little management practices to reduce the virus spread in their farmers. The fact that the correlation show that PLRV was significantly less in seed farms than in non-seed farms could be attributed to the fact that, the symptoms of this virus are the most obvious in showing that the potato plant has a virus disease. Hence the few farmers who said they had some knowledge of virus diseases could easily identify this symptom and uproot the affected crop. This could have led to the low incidence of PLRV in seed farms than in the non-seed farms. This shows that if the farmers were taught on the proper management practices of the virus diseases on their farms, (including how to identify symptoms of the other viruses), much more would be achieved in reducing the virus incidence in the farm-based seed potato production systems.

The correlation showing that higher AEZs had less aphids and also less PLRV and PVY shows that it is safer to encourage potato seed production in the higher altitude potato growing areas than in the lower altitude areas. This is because there is less virus disease (especially the more serious PLRV and PVY) and aphid pressure in the higher AEZs. The fact that a similar reduction in the overall visual virus incidence was not reflected in the correlation with the altitude could be attributed to the widespread use of non-certified seed. This could have led to the spread of the viruses to all AEZs through infected seed. To correct this situation, farmers would need to get a fresh supply of certified seed, and be trained on proper virus and aphid control measures so as to maintain a relatively healthy crop over a long period for use as seed before there would be need to replenish their crop again with certified seed.

CHAPTER FOUR

MONITORING OF APHIDS AND VIRUS DISEASES ON SEED POTATO FARMS UNDER DIFFERENT MANAGEMENT PRACTISES

4.1 INTRODUCTION

Different seed potato farmers have different management practises for potato pests and diseases especially virus diseases and their aphid vectors. Due to the economic difficulties or the limitations in obtaining certified seed potato, most farmers resort to selecting seed from the previous year's crop, whose yield and quality may have been affected by virus diseases. In addition, most farmers do not practice control measures for aphids like spraying either due to lack of resources or lack of knowledge on the effect the aphids could have in spreading virus diseases in the potato crop. Aphid vectors of the virus diseases in potatoes hence spread the virus diseases further if not properly controlled. The basic problem facing potato production in Kenya is low yields due to diseases and insect pests (Kinyae *et. al.* 1994). Among these pests and diseases, the key constraint in the production of seed potatoes is the management of virus diseases and their aphid vectors (Ngugi, 1983). As aphids are the main vectors of potato viruses, their control is very important in potato seed production. These aphids cause more damage by transmitting viruses than by feeding on the plants (Raman, 1985). Crop degeneration caused by these viruses necessitates constant renewal of potato seed by the farmers. This is however difficult in most developing countries including Kenya because of economic difficulties and limitations to an efficient and sufficient production of healthy seed. High seed production costs place the price of seed beyond the reach of poor farmers (Salazar, 1996). It is therefore important to understand how farmers handle their own seed potato production against virus diseases and their aphid vectors. A monitoring system for aphids and viruses that is low cost, not time consuming and acceptable to the seed potato farmers needs to be developed using a participatory approach. This would show how different management practices for aphids and virus diseases affect the virus incidence and aphid populations in the farms. Thereafter, ways would be worked out to improve on the control of these aphids and virus diseases and increase yields on the potato crop. This study was therefore done to determine the virus disease incidence and aphid infestation in the farmers' seed potato crop under different management practices.

4.2 MATERIALS AND METHODS

4.2.1 Site selection

Four farms were selected for continued monitoring of aphids and virus diseases under farmer management practices in Tigoni area. The 1st farm was a school farm where no aphid spraying and virus management practices such as use of certified seed and rouging virus symptomatic plants were practiced. The 2nd farm was a research center seed multiplication farm where strict aphid control and virus management measures were practiced. The 3rd and 4th farms were small-scale farmers sites where half measures of aphids and virus diseases control were practiced. The 3rd farm was located in an area with no other potato field nearby as a possible source of aphids but the farmer practised no aphid spraying and bought seed from another farmer which was highly virus infested. In the 4th farm, the farmer selected his own seed from previously certified seed and practiced rouging of virus infested plants but only sprayed when he thought necessary. All these farms were monitored for 2 seasons, the short rains season of October 2001-February 2002 and in the long rains season of March-July 2002. Six yellow water traps (Plate 8) were put in each farm in about ¼ hectare equidistantly spaced to trap the flying winged aphids. These were filled to about ¾ level with water and some liquid detergent (GEAPOL - Heavy duty surface and dish washing detergent) added to break surface tension so that insects trapped could sink to the bottom and not fly away or be swept away. Aphid and virus sampling was done every 2 weeks from crop emergence to maturity. At each farm the approximate size of the potato field monitored was quarter a hectare regardless of the total size of the farm.

Plate 8: Water traps at the On-farm monitoring sites

4.2.2 Aphid Sampling

4.2.2.1 Aphid sampling in the water traps. The water traps were separately emptied and all aphids trapped were transferred to Universal Bottles containing 60% alcohol so as to preserve the aphids. These aphids were counted and later identified and their populations and species recorded. The water traps were reset fortnightly after each sampling.

4.2.2.2. Aphid sampling on leaves. 30 plants were selected at random and from each plant, 3 compound leaves were picked from the top, middle and bottom positions and put in separate sample bags, which were put in a cool box. Aphid population counts and species identified under a stereo telescopic dissecting microscope were later recorded.

4.2.3 Virus Sampling

4.2.3.1 Assessment of visual virus incidence. The Plot (Potato farm) was divided into 5 equal portions. In each portion, 20 randomly selected plants were observed for virus disease symptoms making a total of 100 plants in the 5 portions. The total number of plants showing virus symptoms was then expressed as a proportion of the total number of plants observed in the farm (i.e. 100). This gave the virus disease incidence (%) in that farm and this was recorded for each farm.

4.2.3.2 Viruses Serological assay. During the second season (Long rains) leaf samples were also taken for an ELISA test 45 days after emergence. Leaves showing virus disease symptoms were taken from 10 randomly selected plants (10 samples) per farm. These were put in a cool box and then in a refrigerator at 4 ^{0}C before they were processed and serologically assayed for the presence of PLRV, PVY, PVX and PVS. DAS – ELISA method (Clark and Adams, 1977 - Appendix 2) was used to determine the viruses present. 8 samples per farm were tested.
The data was subjected to analysis of variance (ANOVA) using the Genstat computer program.

4.3 RESULTS

4.3.1 Aphid populations. For both seasons, there were no significant differences in the mean aphid numbers either on leaves or in the water traps between the different farms (P=0.05).

However, there was a highly significant difference in the virus incidence (P<0.001) between the different farms in both seasons (Table 4.1).

Table 4.1 Mean apterae aphid numbers on leaves, alate aphids in the water traps and visual virus incidence (%) in 4 farms in Tigoni area during the short rains (October 2001-February 2002) and the long rains (March – July 2002).

	Short rains 2001			Long rains 2002		
Farms	Apterae aphids	Alate aphids	Virus incidence (%)	Apterae	Alates	Virus %
Farm 1	241.5	612.75	54.75	80.75	257.75	63.5
Farm 2	15.75	166	10.75	23.25	111.75	4
Farm 3	4.75	69	59.75	38.5	40.25	49
Farm 4	227	362.75	31	35.75	23.5	25.25
Mean	**122.25**	**302.63**	**39.06**	**44.56**	**108.31**	**35.44**
F-test (P<0.05)	ns	ns	***	ns	ns	***
L.S.D	257.4	421.2	8.74	68.2	206	5.42

***** = Significant difference at P<0.001 ns= No significant difference at P<0.05**

There were generally more aphids during the short rains 2001 than in the long rains 2002 season. The differences were found to be significant (P<0.05). The aphid population on leaves generally increased with growth of the crop then decreased as the crop aged to maturity. Aphid numbers were highest on the bottom leaves followed by the middle leaves and lowest at the top leaves. However, the difference in aphid numbers at the different leaf positions was only significant (P<0.05) in the 1st week of sampling during the 1st season but not in the other sampling weeks. Farm 1 had the highest mean aphid numbers in both seasons. Farm 4 had high aphid numbers in season 1 but the numbers were relatively low in the second season. Aphid numbers in farms 2 and 3 were low in both seasons. Farms 1 and 4 had higher mean aphid numbers than farms 2 and 3 in the short rains 2001 season. Farm 1 continued to maintain higher aphid numbers than any of the other 3 farms in the long rains 2002 season while aphid numbers in farm 4 reduced drastically throughout this season (Fig. 4.1).

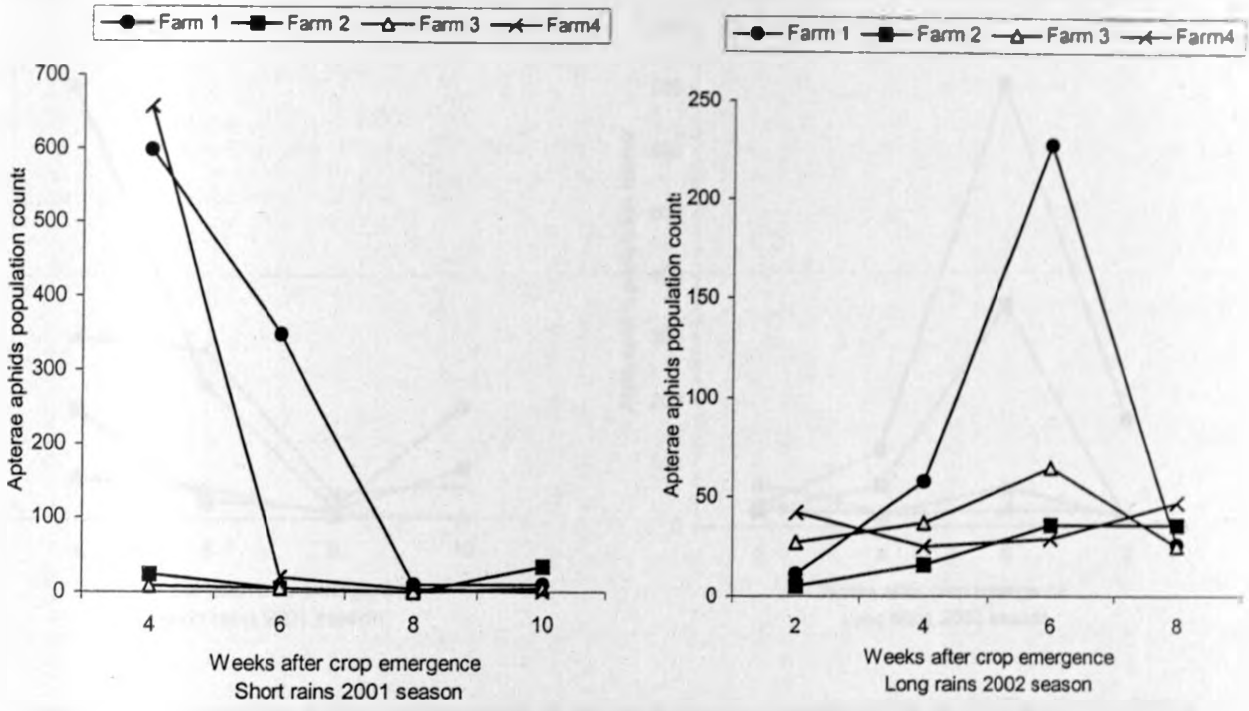


Figure 4.1: Mean number of apterae aphids on leaves at 4 potato farms in the Tigoni area during the short rains 2001 and the long rains 2002 seasons.

In the water traps, the trend in the aphid populations was closely similar to that shown on the leaves (Fig. 4.2). During the short rains 2001 season, farm 1 had on average higher aphid numbers in the water traps than each of the other 3 farms. This was followed by farm 4, which had higher aphid numbers on average than farms 2 and 3 in this season. In the long rains 2002 season, aphid numbers in the water traps was again highest in farm 1 than in any of the other 3 farms but populations in farm 4 were the lowest in this season.

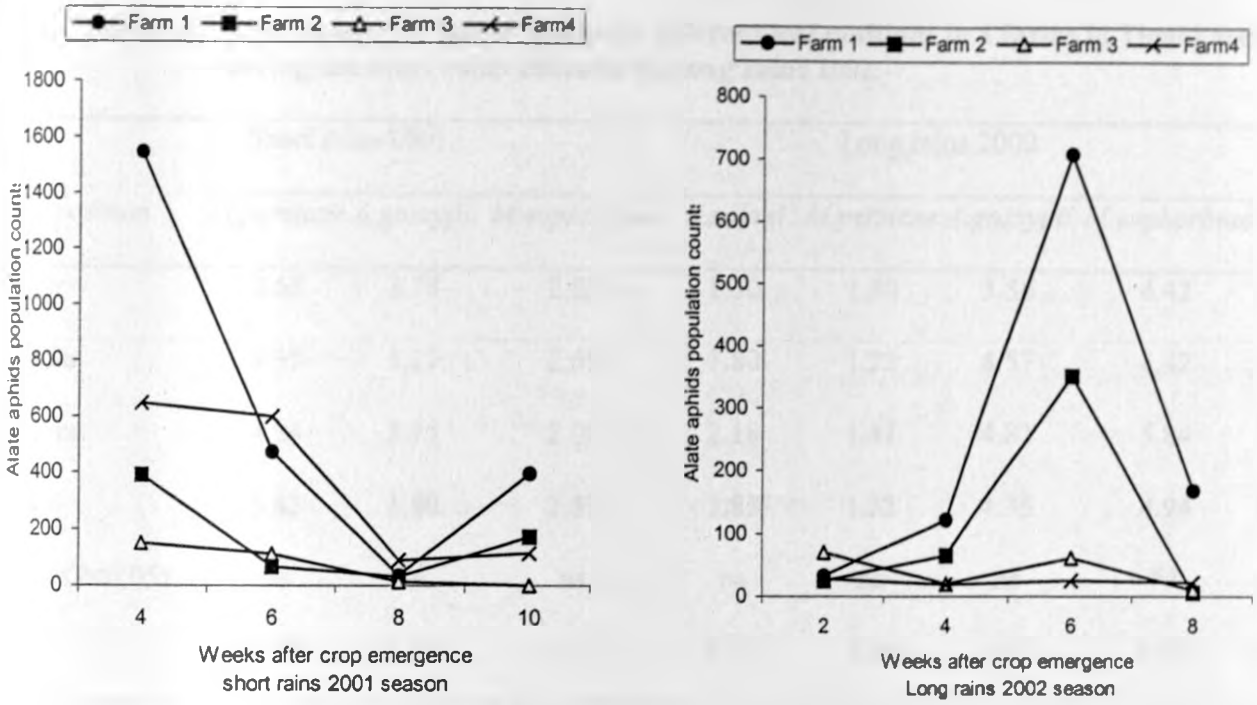


Figure 4.2:Mean number of alate aphids caught in the water traps at 4 potato farms in the Tigoni area during the short rains 2001 and the long rains 2002 seasons.

4.3.2 Aphid species. Tables 4.2 and 4.3 show aphid species identified from the leaves and water traps during the short rains 2001 and the long rains 2002 seasons. The species included *A. gossypii, M. euphorbiae, M. persicae and A. solani.*

4.3.2.1 Aphid species on leaves

During the short rains 2001 season, there were significant differences ($P<0.05$) between the different sampling weeks in the population of *M.persicae, M.euphorbiae and A.solani.* Only *A. gossypii* species populations were not significantly different between the sampling dates. However, there were no significant differences ($P=0.05$) between the different leaf positions in any of the aphid species numbers in this season.

In the long rains 2002 season, there were significant differences between the different sampling weeks in the populations of *M.persicae* ($P<0.05$) and *A.gossypii* ($P<0.01$). There were also highly significant differences ($P<0.001$) between the different sampling weeks in the number of *M.euphorbiae* species. A comparison of the aphid species at the different leaf positions showed that, only *M.euphorbiae* species populations were significantly different ($P<0.01$) at the different leaf positions in this season. Bottom leaves had the significantly higher *M.euphorbiae* numbers than the middle and upper positioned leaves.

Table4.2. Mean number of aphid species at different leaf positions in 4 farms in Tigoni area during the short rains 2001and the long rains 2002.

	Short rains 2001				Long rains 2002			
Leaf position	*M.persicae*	*A.gossypii*	*M.euphorbiae*	*A.solani*	*M.persicae*	*A.gossypii*	*M.euphorbiae*	*A.sola.*
Upper	2.65	2.78	2.83	1.50	1.30	3.56	4.42	0.87
Middle	4.39	3.17	2.65	1.80	1.22	4.57	4.42	0.95
Bottom	4.24	3.75	2.06	2.18	1.41	4.81	5.84	1.05
Mean	**3.82**	**3.30**	**2.53**	**1.85**	**1.32**	**4.35**	**4.94**	**0.96**
F-test (P<0.05)	ns	ns	ns	ns	ns	ns	**	ns
L.S.D	1.39	5.48	1.12	0.46	0.39	0.85	0.74	0.47

Data transformed square root (x+0.5)
**= Significant at P<0.01 Level, ns= Not significant at P<0.05

Macrosiphum euphorbiae populations were significantly different between the 2 seasons (P<0.05). The Long rains 2002 season had higher populations of *M.euphorbiae* than the short rains 2001 season. The populations of the other species were not significantly different between the seasons (P=0.05).

4.3.2.2 Aphid species in the water traps

Only three Aphid species *A. gossypii, M. euphorbiae* and *M. persicae* were present in the water traps (Table 4.3). *A solani*, which was found in small numbers on leaves, was completely absent in the water traps. The populations of *M.persicae* were significantly different between the different farms (P<0.001) in the short rains 2001 season. Populations of *A. gossypii* were also significantly different between the different farms in this season (P<0.05). Farms 1 and 4 had significantly higher numbers of both the *M.persicae* and *A. gossypii* species than farms 2 and 3. *M. euphorbiae* species was not significantly different in their numbers in this season between the different farms (P=0.05). In the long rains season, no significant differences were observed in the numbers of any of the aphid species between the different farms (P=0.05).

Table 4.3 Mean number of aphid species from water traps in 4 farms in Tigoni area during the short rains 2001 and the long rains 2002 seasons.

	Short rains 2001			Long rains 2002		
Farms	*M.persicae*	*A.gossypii*	*M.euphorbiae*	*M.persicae*	*A.gossypii*	*M.euphorbiae*
Farm 1	2.35	24.65	2.40	1.12	15.25	5.02
Farm 2	1.66	12.62	2.35	0.71	10.40	2.12
Farm 3	0.91	9.53	1.35	0.71	5.61	3.12
Farm 4	2.45	18.87	1.50	1.22	4.33	2.12
Mean	**1.84**	**16.42**	**1.90**	**0.94**	**8.90**	**3.10**
F-test (P<0.05)	***	*	ns	ns	ns	ns
L.S.D (0.05)	0.12	8.12	1.07	0.54	1.02	1.9

Data transformed square root (x+0.5)
***= Significant at P<0.01 Level, *= Significant at P<0.05 Level, ns= Not significant at P<0.05

There were significant differences in the numbers of all aphid species between the 2 seasons, (P<0.01). There were higher populations of *M.persicae and A.gossypii* species in the water traps during the short rains 2001 season than in the long rains 2002 season. *M.euphorbiae* populations were higher in the long rains season than in the short rains season. From the leaves, *M.persicae* and *Aulacorthum solani* populations were higher during the short rains season while *M.euphorbiae* and *A.gossypii* species had higher populations in the long rains 2002 than in the short rains 2001 season.

The trend from the identification of the aphids collected revealed that *Aphis gossypii* was the most prevalent species both on leaves and in the water traps (Figure 4.3 and 4.4). Its population was higher than any other species in both the short and the long rain seasons. However, in the long rains season *Macrosiphum euphorbiae* population increased as the season progressed becoming more in number than *Aphis gossypii* on leaves towards the end of the season in the last half of the season in 3 samplings (Figure 4.3). *M. euphorbiae* population in water traps also increased in the same period though their numbers were still lower than the *A.gossypii* species numbers (Figure 4.4). *Myzus persicae* numbers ranked 3rd while *Aulacorthum solani* species numbers were the least on leaves and absent in the water traps.

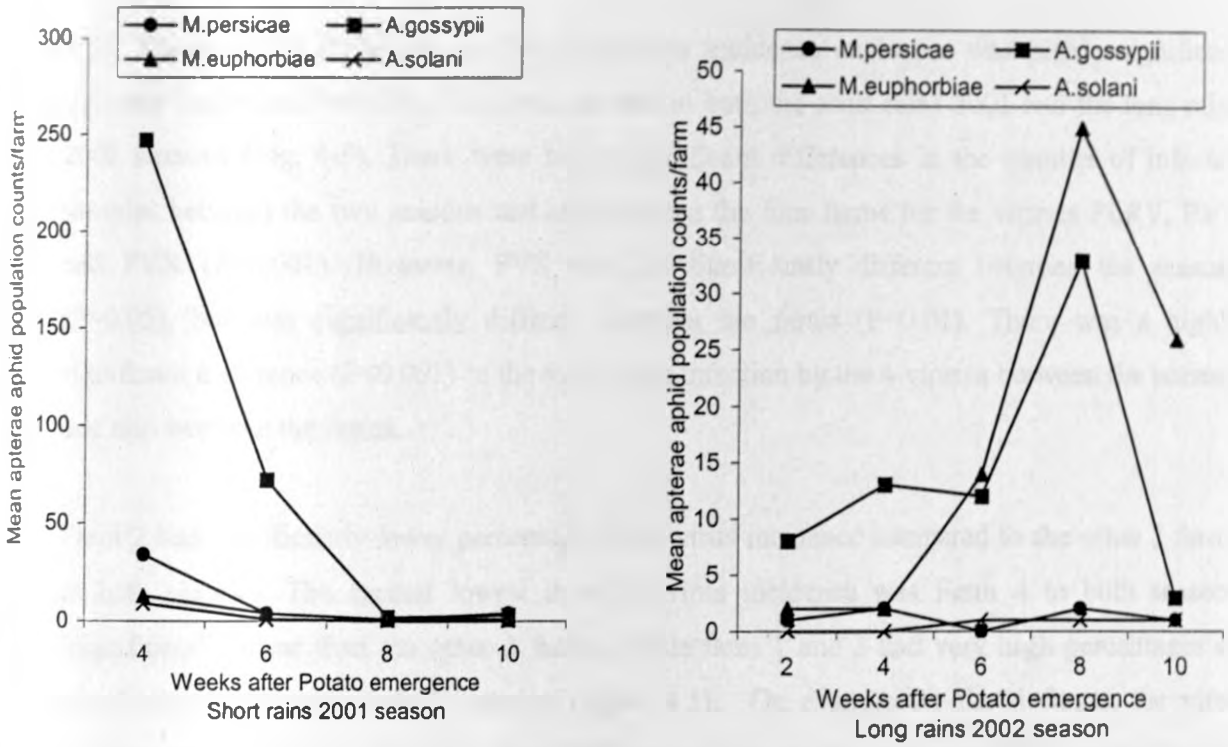


Figure 4.3. The Mean populations of apterae aphid Species on leaves in 4 farms in Tigoni area during the short rains of 2001 and long rains of 2002

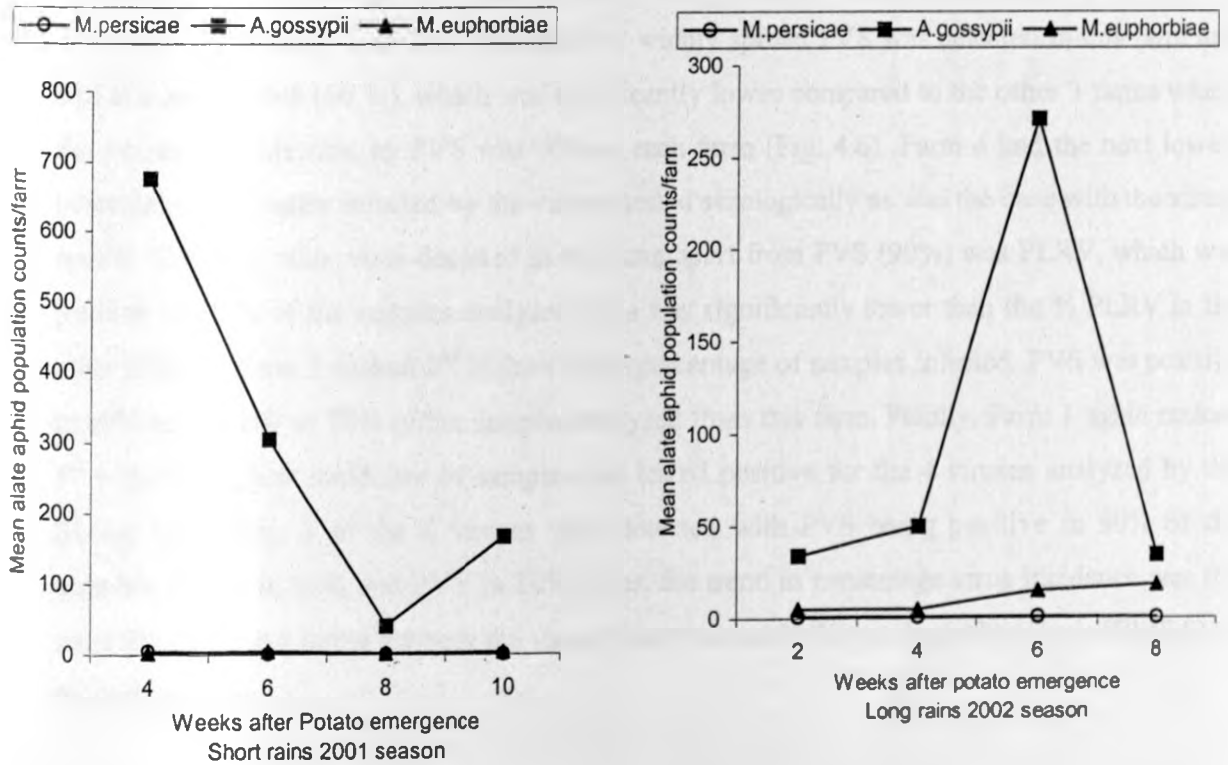


Figure 4.4:The populations of alate aphid Species in the water traps in 4 farms in Tigoni area during the short rains 2001 and the long rains 2002.

4.3.3 Viruses. The difference in the visual virus incidence on leaves was highly significant between the farms ($P<0.001$). This was the case in both the short rains 2001 and the long rains 2002 seasons (Fig. 4.5). There were highly significant differences in the number of infected samples between the two seasons and also between the four farms for the viruses PLRV, PVY and PVX ($P<0.001$). However, PVS was not significantly different between the seasons ($P=0.05$), but was significantly different between the farms ($P<0.01$). There was a highly significant difference ($P<0.001$) in the mean virus infection by the 4 viruses between the seasons and also between the farms.

Farm 2 had significantly lower percentage visual virus incidence compared to the other 3 farms in both seasons. The second lowest in visual virus incidence was Farm 4 in both seasons (significantly lower than the other 2 farms), while farm 1 and 3 had very high percentages of visual virus incidence in both seasons (figure 4.5). On average for the 4 farms, the virus incidence was higher in the short rains 2001 season than in the long rains 2002 season though this was not statistically significant ($P= 0.05$).

The ELISA results also showed that, of the 4 viruses tested (PVS, PLRV, PVY and PVX), farm 2 was only infected by one. Only the mild but widely spread PVS was detected in this farm and still at a lower level (50 %), which was significantly lower compared to the other 3 farms where the percentage infection by PVS was 90% in each farm (Fig. 4.6). Farm 4 had the next lowest percentage of samples infected by the viruses tested serologically as was the case with the visual results. The only other virus detected in this farm apart from PVS (90%) was PLRV, which was positive in 10 % of the samples analyzed. This was significantly lower than the % PLRV in the other 2 farms. Farm 3 ranked 2nd highest in the percentage of samples infected. PVS was positive in 90% and PLRV in 70% of the samples analyzed from this farm. Finally, Farm 1 again ranked 1st with the highest incidence of samples that tested positive for the 4 viruses analyzed by the ELISA test. Here, 3 of the 4 viruses were detected with PVS being positive in 90% of the samples, PLRV in 80% and PVY in 10%. Thus, the trend in percentage virus incidence was the same through the 4 farms for both the visual observation and the serological analysis (ELISA) of the leaf samples.

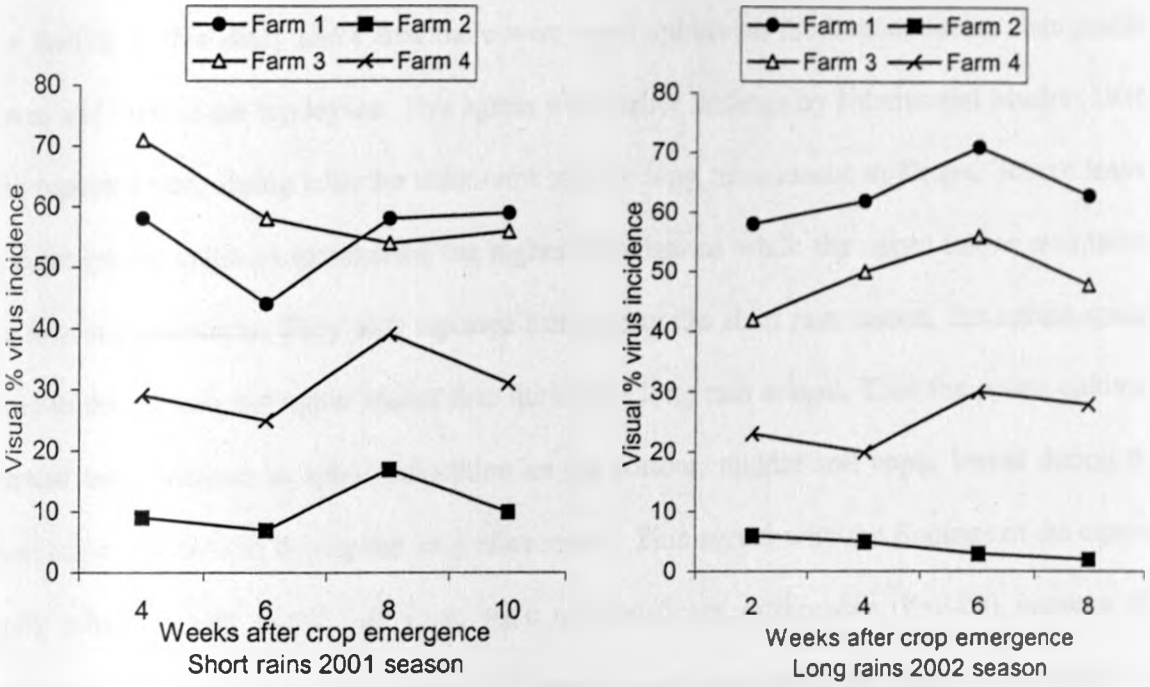


Figure 4.5: Visual virus incidence (%) in the 4 farms in Tigoni area during the short rains 2001 and the long rains 2002 seasons.

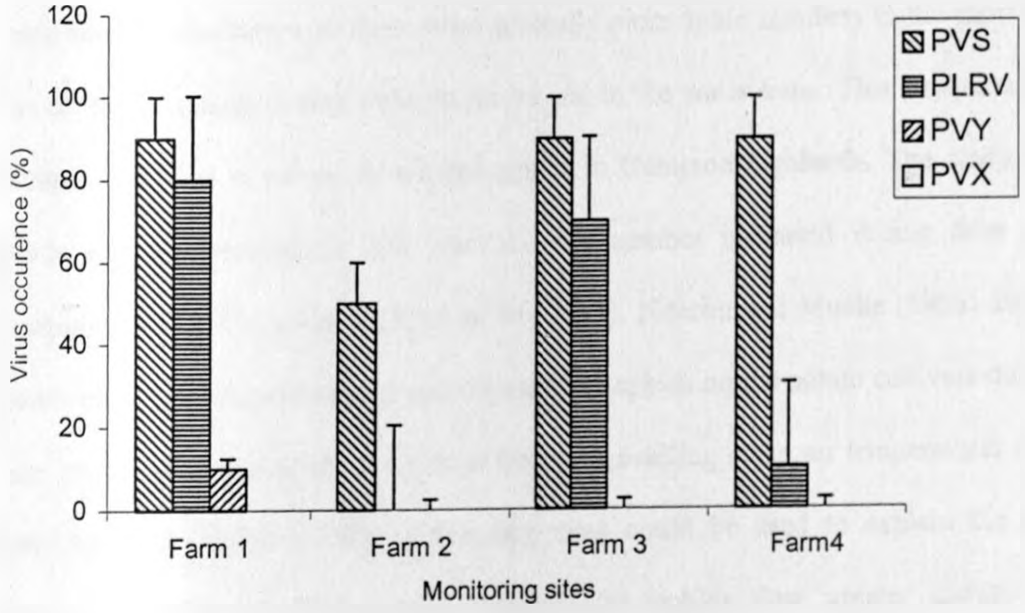


Figure 4.6: Occurrence (%) of four viruses at the 4 potato farms in Tigoni area during the short rains of 2001and the long rains of 2002 (results of the ELISA tests)

DISCUSSION

The results of this study show that there were more aphids on the bottom leaves than middle leaves and least in the top leaves. This agrees with earlier findings by Nderitu and Mueke (1986) who reported that, during both the short rains and the long rains season in Kenya, bottom leaves of eight potato cultivars maintained the highest populations while the upper leaves maintained the lowest populations. They also reported that, during the short rain season, the aphids spread more to the middle and upper leaves than during the long rain season. Thus the potato cultivars showed less variation in aphid infestation on the bottom, middle and upper leaves during the short rains season than during the long rains season. This agrees with the findings of the current study where it was found that there were no significant differences ($P=0.05$) between the different leaf positions in any of the aphid species numbers during the short rains season but during the long rains season the *M.euphorbiae* species numbers were significantly different ($P<0.01$) at the different leaf positions.

These results also show that there were generally more aphid numbers in the short rains season than in the long rains season both on leaves and in the water traps. This compares with similar findings earlier in a survey of winged aphids in Cameron highlands. The study showed that aphids occurred throughout the year and the number increased during drier months and decreased during wet periods (Syed *et. al.*, 1992). Nderitu and Mueke (1986) also found that there were higher populations of apterae and alate aphids on the potato cultivars during the short rains season than during the long rains season. Prevailing mean air temperatures (27° c) in the short rains compared to 22°c in the long rains could be used to explain the higher aphid population during the short rains. Probably the aphids flew greater distances when the temperatures were higher. It has been reported that high altitude affects the activity of aphids due to limited flight (Bertschinger, 1992). Radcliffe (1982) reported that temperatures of less than

17.8°c greatly restrict the number of flights of *M. persicae* in the laboratory. This observation is in agreement with the finding by Thackray *et al.*, (2002) that rainfall promotes growth of weeds and pasture plants, which aphids can build on. The results of this chapter also show that the virus incidence was higher in the short rains season than in the long rain season. This compared well with the survey results (Chapter 3) where it was found that the aphid number and the virus incidence was higher in the lower altitude areas than in the higher altitude areas where the rainfall is more and the temperatures lower than the low altitude zones.

Aphis gossypii was the predominant aphid species followed by *Macrosiphum euphorbiae* then *Myzus persicae* and lastly *Aulacorthum solani*, which was almost absent. This trend was the same in both the water traps as well as for the aphid numbers on leaves. However, in the water traps, *A. solani* was completely absent and only the other 3 species *Aphis gossypii, Macrosiphum euphorbiae* and *Myzus persicae* were found. These results agree with similar results of earlier work done at Souss valley in Morocco where aphid populations were monitored by weekly aphid counts on plants and captures of alates in yellow water pans. Three species, *Myzus persicae* (Sulzer), *Macrosiphum euphorbiae* (Thomas) and *Aphis gossypii* (Glover) were found colonising the potato plant. However, the order of abundance of these species in Morocco was different from that found in this study. The most abundant species in the Morocco study was *Myzus persicae* for both alate captures and apterae counts throughout the growing season. The second most abundant was *A. gossypii* and the least frequent was *M. euphorbiae* (Hanafi, 1992). However, other studies here in Kenya agree with the findings of the current study. Nderitu and Mueke (1986) found that *A. gossypii* was the dominant aphid species infesting the potato cultivars in the field. They further reported that, *A. gossypii* was the dominant species during the short rains season (1980). It was also the dominant aphid species in the early and towards the late part of the long rain season (1981). However they found that, at the middle of the long rain

season, potato cultivars were heavily infested by *M. euphorbiae* and to a less extent by *M. persicae* aphid species. This agrees with the findings of this current study where it was found that *A. gossypii* was the predominant species in the short rains 2001 season and in the early part of the long rains 2002 season. *M. euphorbiae* populations then increased greatly to surpass the populations of *A. gossypii* on leaves from the middle of the long rains 2002 to the end of that season.

This on-farm monitoring study also shows that the virus incidence both visual and serological was highest in Farm 1 and lowest in Farm 2 on average for both seasons. Similarly aphid numbers were highest in Farm 1 and lowest in Farm 2 in both seasons. Farm 1 was a farm where no certified seed was used and also no spraying was done to control the aphids. On the other hand, farm 2 was where certified seed was planted and aphids were controlled by spraying as recommended. This shows that proper farmer management practices for aphids and virus diseases control plays a big role in reducing the severity of virus disease incidence and aphid infestation in farmer's seed potato crop. Insecticides use in the control of aphids is an indirect control of potato viruses such as PLRV and PVY (Woodford and Gordon, 1990). Radcliffe (1982) observed that insecticides applied in furrows at planting or side dressed at the time of emergence are more effective in suppressing aphid populations and also minimize virus spread in potato fields. Nderitu (1983) found use of Oxydemeton methyl and dimethoate as foliar sprays and disulfalton and carbofuran as soil insecticides to be efficient in reducing aphid population in potato plots. PLRV is persistently transmitted and it is therefore, appropriate to use insecticides as a major component of its control (Hanafi, 2000). Certified seed is expensive and sometimes unavailable (Ajanga, 1993). However, Were (1996) found that every farm in Kiambu had aphid infestation, but virus diseases incidences were low. He attributed the low incidence to usage of certified seeds by the farmers.

Farm 3 had very low aphid numbers but high virus incidence. The low aphid numbers could be attributed to the fact that this farm was isolated and surrounded by tea, coffee, maize and no solanaceae plants in the neighbourhood hence little or no other sources of aphids. However, this farmer planted uncertified seed, which were heavily infected by viruses. Hence the virus incidence in this farm was quite high and the source of the viruses could therefore have been seed borne rather than aphid vector transmitted. Farm 4 was owned by a farmer who had knowledge on how to select relatively virus free seed potato and also monitor for aphids and control them when necessary. Hence, though during the first sampling the aphid numbers were very high, the numbers drastically reduced in the subsequent samplings due to control measures applied by the farmer. The virus incidence was also the second lowest after that of the research station in both seasons. This could be attributed to the ability of this farmer to identify the virus diseased plants and rogue apart from being able to select his own relatively clean seeds for planting. These results show that, Farmer management practises have a big impact on the aphid populations and the virus incidence on farmer based seed potato production systems in Kenya. However, very little has been documented on studies done on farmers' fields on their management practices to control aphids and virus diseases in seed potatoes. More studies are therefore required to document this so that information gathered can be used to develop interventions that will help the farmers improve their aphid and virus diseases management practises. This will in turn help them increase their potato yields per unit area.

CHAPTER FIVE

EFFECTS OF SEED QUALITY DEGENERATION DUE TO VIRUS INFECTION AND APHID INFESTATION ON YIELDS

5.1 INTRODUCTION

Potato (*Solanum tuberosum* L) is the world's fourth most important food crop after wheat, rice and maize (CIP, 1996). In Kenya its importance in recent years has grown rapidly and it is now the second most important food crop after maize in terms of production volume (Ng'ang'a *et. al.*, 1994; Anon., 2002). Although it is an important crop, the national average of 4.4 tons/ha is low compared to the world average of 17tons/ha in developed and 13 tons/ha in developing countries (FAO, 1992; FAO, 1995). It is possible to realize 40tons/ha under research station conditions in the country (Lungaho *et. al.*, 1997). The increased demand for potatoes as a staple food in rural areas and as a 'fast' food (French fries and potato crisps) in urban centres, calls for increased production in the farmer's fields. However, the basic problem facing potato production in Kenya is low yields due to diseases and insect pests (Kinyae *et. al.*, 1994). Although the total land under potato cultivation has increased four-fold between 1965 (27,000 ha.) and 2000 (108,000 ha.) (Anon., 2002), yields per unit area have continually declined (Barton *et. al.*, 1997). The low national average yield is mainly due to degeneration of the seeds due to a build up of viral, fungal and bacterial pathogens, including aphids and the potato tuber moth pests. A solution to these pest and disease problems would result in increased certified seed and ware potato yields per unit area and an expansion of the area under seed and ware potato production. Viruses and aphids are the key constraints to production of certified seed potatoes and constitute an important yield constraint. Efforts to address virus diseases and aphid vectors are therefore needed if the anticipated benefits of farmer-based seed potato production are to be realized. Some viruses, such as the potato leaf roll (PLRV) cause yield losses of up to 90% in highly susceptible cultivars (Harrison, 1984). Potato virus X (PVX) and Potato virus Y (PVY) alone or together interact with PLRV and may significantly decrease resistance to PLRV. Crop degeneration caused by these viruses necessitates constant renewal of potato seed by the farmers. However not much study has been done in Kenya to assess the relationship between the virus incidence, aphid populations, seed degeneration and yield loss in potato varieties. The study was therefore conducted to assess yield loss and seed potato quality degeneration due to virus infection and aphid infestation.

5.2 MATERIALS AND METHODS

The experiments were carried out at 2 sites, the National Potato Research Centre (NPRC) Tigoni (Altitude 2150 m) and the University of Nairobi's field station, Kabete (Altitude 1953m).

5.2.1 Experimental layout and design

The experiment was laid on a completely randomized block design (CRBD) with split-split plot arrangement (Plate 9). There were 16 treatments in total, and they included, 4 potato varieties Tigoni, Asante, Nyayo and Kerr's Pink. For each variety, two types of seed were planted namely certified seed from NPRC Tigoni and Farmer's uncertified seed. Main plots were composed of the spraying treatment (sprayed or not sprayed); the Subplots (split plots) had the seed type (certified or not certified) while the varieties were put in the sub-sub plots (split-split plots).

The 1st main plot which was composed of 8 sub-subplots was sprayed with aphid control chemicals (Karate and Metasystox) at the recommended rates and spraying intervals throughout the growth season of the potatoes. The other main plot (8 sub-subplots) was not sprayed with the aphicide throughout the growth period of the potato. This was replicated 3 times (3 blocks) giving a total of 48 plots at each of the 2 sites (in Tigoni and Kabete). All other recommended agronomic practices from planting, weeding and fungicide application were applied equally to all plots. Each sub-subplot had 4 rows each with 10 hills (hence 40 plants per sub-subplot). Plants were spaced at 75 cm between the rows and 30 cm between the hills within each row. Each Sub-subplot was 3mx3m with 1m between the plots and 3m between the blocks (reps) and the half blocks (Main plots - spray side and the non-spray side). Polythene sheeting (Plate 10) was used to prevent chemical drift from spray to non-spray plots during the application of the aphid control chemical spray.

Six yellow water traps were placed in each site, one trap at the center of each half block (main plot) to trap the flying winged aphids. Water was filled ¾ full in each basin and a liquid detergent (GEAPOL - Heavy duty surface and dish washing detergent) added to break surface tension so as to have insects trapped here sink to the bottom. In the 2nd season, the water traps were placed during planting time at both Tigoni and Kabete sites. This was done deliberately to capture any aphids that might be there before the crop emerges unlike in the 1st season when traps were put after the crop had emerged.

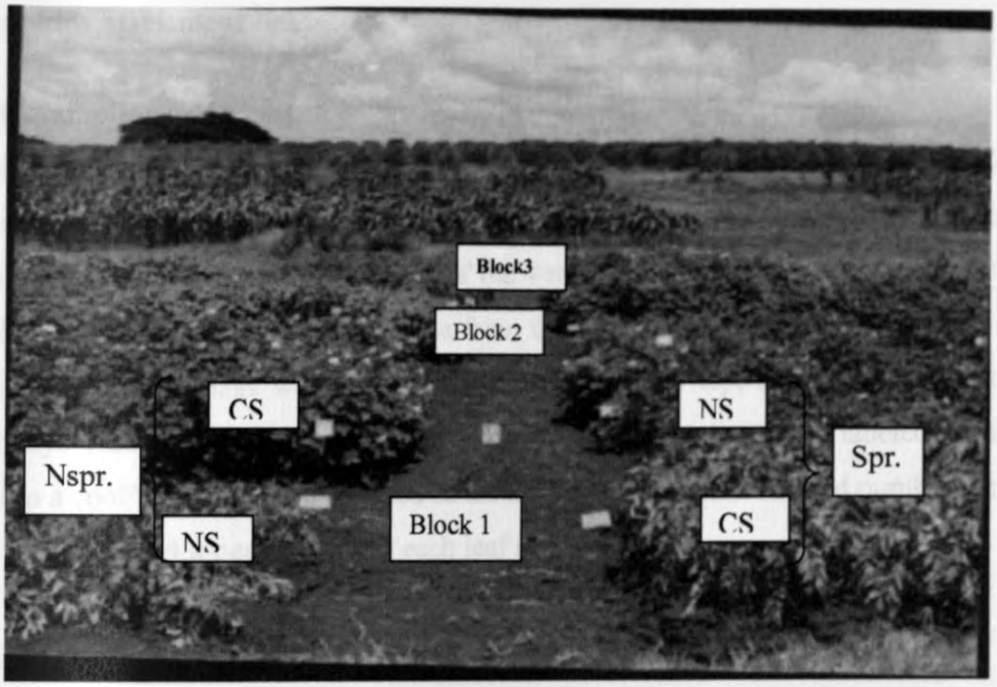


Plate 9: Field layout of the on-station experiments

For each block

CS= certified seed (4 Plots with different varieties-Tigoni, Asante, Nyayo and Kerr's pink)

NS=non-certified seed (4 Plots with different varieties-Tigoni, Asante, Nyayo and Kerr's pink)

Spr.= 8 plots (4 certified, 4 non-certified) sprayed with an aphid control pesticide.

Nspr.= 8 plots (4 certified, 4 non-certified) not sprayed with an aphid control pesticide.

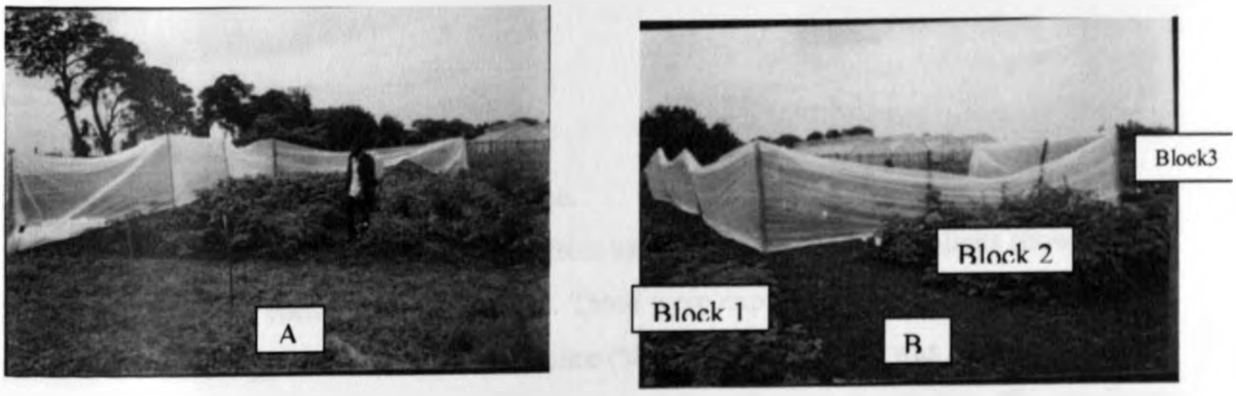


Plate 10: Use of polythene sheeting to prevent chemical drift.

(A) Side plots, (Block 1 and 3) (B) Middle plots, (Block 2)

5.2.2 Samplings

5.2.2.1 Aphids assessment

(i) Aphid Sampling on Leaves

Sampling was done fortnightly from crop emergence to maturity. During each sampling, 15 leaves were picked from each plot. These were picked from 5 plants randomly selected from the plot but ensuring at least 1plant from each of the 4 rows. 3 leaves were picked from each plant, one leaf from the top part of the plant, one from the middle position and one from the bottom position. 3 sampling bags were used for each plot for the top, middle and bottom leaves respectively. These were put in separate bags for each plot, and properly labeled. These were then put in a cool box and later examined in the laboratory for aphids. Aphid numbers and aphid species were recorded for each plot and each leaf position.

(ii) Aphid sampling from water traps

This was done every two weeks. In the 1st season, four samplings were done while in the 2nd season, six samplings were possible for water traps by the time the crop matured. During each sampling, the aphids and other insects trapped in the basins were removed and put in universal bottles with 60% alcohol for preservation of the insects. These were later examined under a telescopic dissecting microscope for counting and identifying species of the trapped winged aphids. After the emptying to remove the aphids and other insects, the water traps were refilled with water and detergent added. The data was subjected to analysis of variance (ANOVA) using the Genstat computer program.

5.2.2.2 Virus assessment

(i) Field assessment of visual virus incidence.

Assessment of the virus incidence was done from each plot. The number of plants showing virus disease symptoms in each plot were counted. These were expressed as a proportion of the total plants in the plot to give virus disease incidence (%) in that plot. This was done for all the 48 plots at each site. In the 1st season, the assessment was done 3 times at each site, 1st immediately after plant emergence, then halfway the season (at 1 $^1/_2$ months after planting) then at crop maturity (3 months). In the 2nd season, Visual virus incidence was also taken 3 times starting from 2 weeks after crop emergence to 2 weeks before dehaulming the crop, which was done at 3 months after planting. Three assessments were done at each site but an extra assessment was

done at Tigoni, as the crop was still green due to a very cold weather in this long rain season in that area. The data was subjected to analysis of variance using the Genstat computer program

(ii) Serological assay of Viruses

(a) Virus indexing on leaf samples. During the 2nd season, leaf samples of virus symptomatic plants were taken at about 1 month after emergence. These were put in a cool box, then in a refrigerator at 4 ^{0}C before being processed for serological assay of PLRV, PVY, PVX and PVS. Direct double antibody sandwich enzyme linked immunosorbent assay (DAS-ELISA) method as described by Clark and Adams (1977) was used.

(b) Virus indexing on tubers. The plants where virus indexing was done on leaves were pegged and their tubers also taken separately during harvesting and labeled for further virus indexing on tubers. This test was done to see if viruses found in leaves had also infected the tubers. DAS-ELISA) method as described by Clark and Adams (1977) was used. The data was then subjected to analysis of variance (ANOVA).

5.2.3 Harvesting;

Yield data was collected and recorded during harvesting. For each plot, the number of tubers per hill (Plate 11) were recorded then average taken to give the average number of tubers per hill in that plot. These were graded per plot to the different sizes (Plate 12) as done by the National Potato Research Centre (NPRC), Tigoni. 4 sizes were used, (i) Ware potatoes (>55mm) (ii) Seed 1 (35-55mm) (iii) Seed 2 (25-35mm) and Chatts (<25mm). Each of these tuber sizes were then weighed and the number of tubers for each size recorded. This was done separately for all the 48 plots. The data on yields were then analyzed to assess the yield loss due to viruses between the certified seed and the virused uncertified farmers' seed. The data was subjected to analysis of variance (ANOVA) using the Genstat computer program

Plate 11: Harvesting tubers per hill. Tubers at each hill put separately for counting number of tubers per hill.

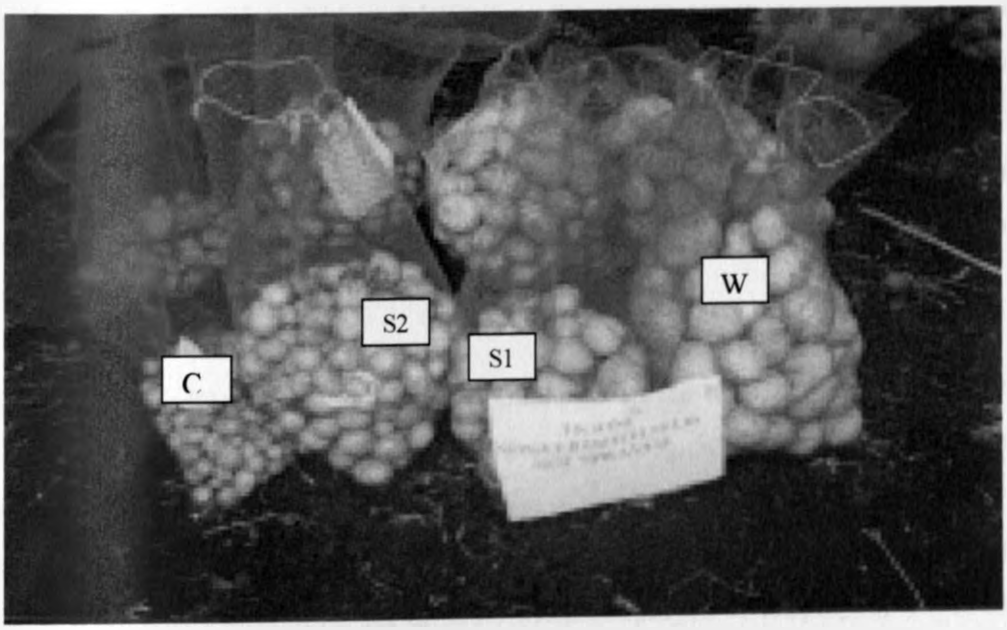


Plate 12: Tuber yields graded to the 4 sizes for each plot.
C=Chatts, S2=Seed2, S1=Seed1, W=Ware potatoes

5.3 RESULTS

5.3.1 APHIDS

5.3.1.1 Assessment of aphid populations in certified and uncertified potato varieties with and without aphid control measures.

The 3 factors, spraying, certification and variety had various effects on aphid population numbers on the potato plants at the 2 sites Tigoni and Kabete during the short rains 2001 and the long rains 2002 seasons. At both the Tigoni and Kabete sites, there were more aphid numbers in the unsprayed plots than the sprayed ones from each variety in both the short rains 2001 and the long rains 2002 seasons. Kerr's pink generally had more aphids than the other varieties. The aphid numbers were always lower in the sprayed plots of each variety and higher in the unsprayed plots irrespective of whether the plot was planted with certified or un-certified seed. The uncertified seed plots had higher aphid populations than the certified seed plots at Tigoni in both seasons but at Kabete there was no clear difference in aphid populations between the certified and the uncertified seed plots. The interaction between spaying and certification also brought clear differences in aphid populations on the potato plants. It was clear that the non-certified plots that were not sprayed had higher aphid populations than the certified plots which were similarly not sprayed. But the sprayed plots had almost the same level of aphid populations in each sampling week whether certified or not certified which was very low compared to the unsprayed plots. The effect of the different factors on aphid population numbers on the potato plants were as follows.

(i) Spraying: At the Tigoni site, the aphid populations in the unsprayed plots remained much higher than in the sprayed plots throughout the 2 seasons (Fig. 5.1) even as the populations were decreasing as the crop matured towards senescence in the short rains 2001 season.

In the long rains 2002 season, it is also clear that though at the beginning of the 1st sampling all aphid totals were at the same level for all plots whether sprayed or unsprayed, the difference in aphid populations kept increasing between the sprayed and the unsprayed plots as the season progressed. Comparison of the trend in aphid build-up for all the sprayed and all the unsprayed plots in this long rains season shows the population building up greatly in the unsprayed plots while decreasing at the same time in the sprayed plots in the progressive sampling weeks

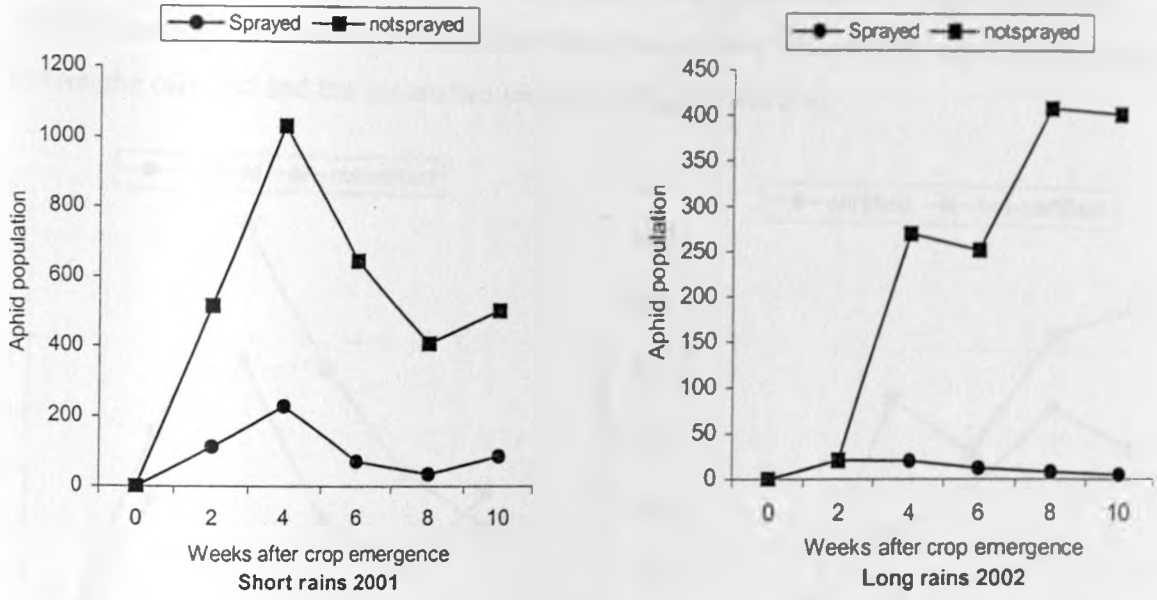


Figure 5.1: Aphid populations on sprayed and unsprayed plots at the Tigoni site in the short rains 2001 and the long rains 2002 seasons.

At the Kabete site, the aphid population in the unsprayed plots was also much higher throughout the 2 seasons compared to the population numbers in the sprayed plots though initially the populations were relatively low in both cases (Fig. 5.2). The difference in the aphid population numbers between the sprayed and the unsprayed plots was highest during the 6th and 4th sampling in the short rains 2001 and the long rains 2002 seasons respectively.

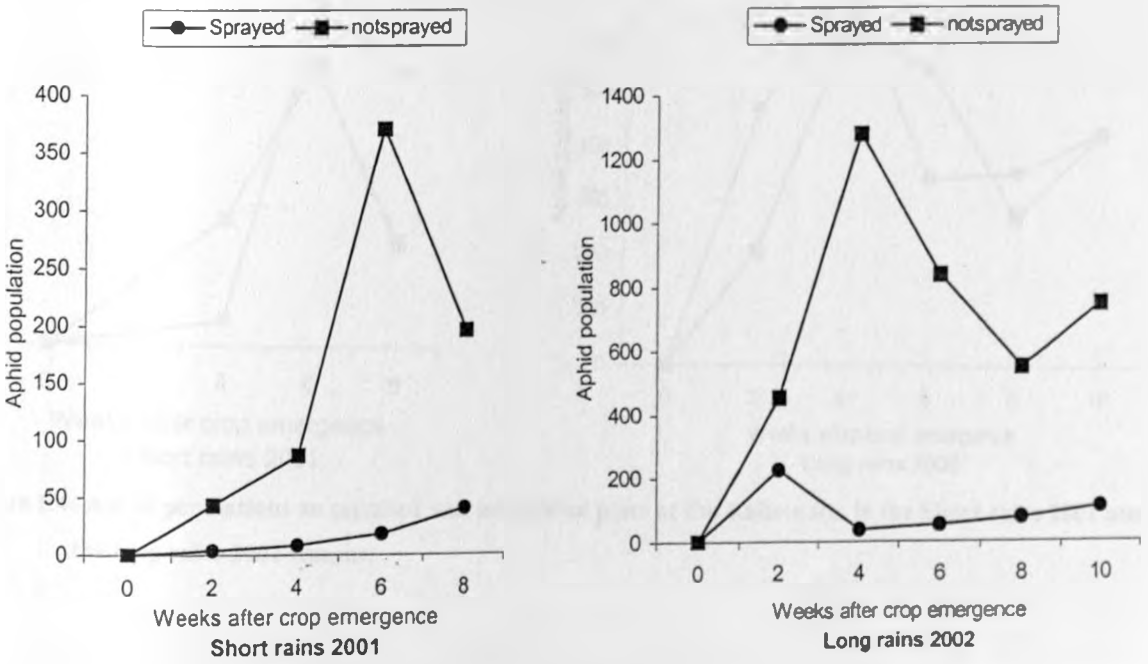


Figure 5.2: Aphid populations on sprayed and unsprayed plots at Kabete in the short rains 2001 and the long rains 2002.

(ii) **Certification:** Uncertified seed plots had higher aphid populations than the certified seed plots at Tigoni in both seasons but at Kabete there was no clear difference in aphid populations between the certified and the uncertified seed plots (Fig 5.3 and 5.4).

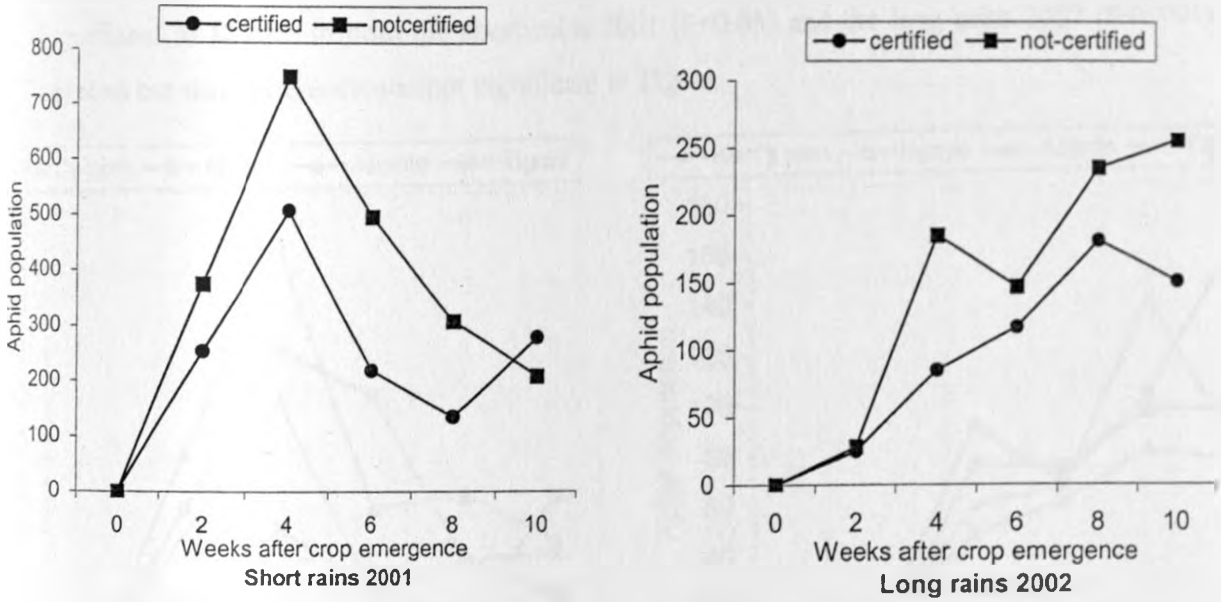


Figure 5.3: Aphid populations on certified and uncertified seed plots at the Tigoni site in the Short rains 2001 and the long rains 2002 seasons.

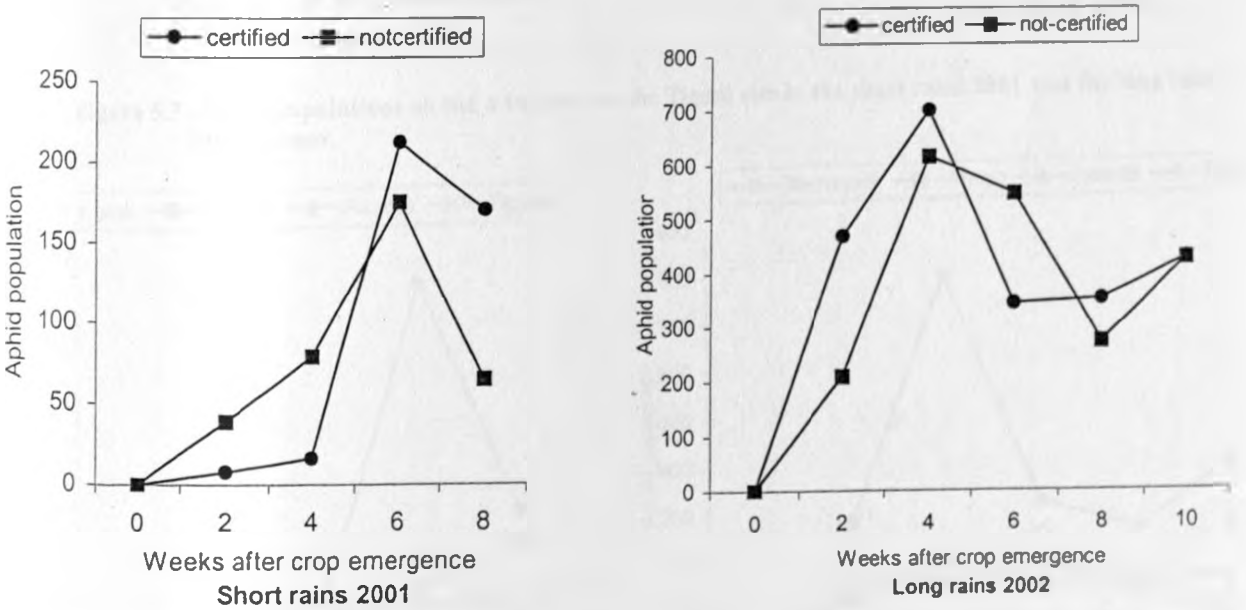


Figure 5.4: Aphid populations on certified and uncertified plots at the Kabete site in the Short rains 2001 and the long rains 2002 seasons.

(iii) **Variety:** Kerr's pink generally had more aphids than the other varieties at both sites in both seasons and this difference was especially distinct at the Kabete site (Fig 5.5 and 5.6). The differences in aphid population numbers between Kerr's pink and the other varieties was actually significant at Kabete in both the short rains 2001 ($P<0.05$) and the long rains 2002 ($P<0.001$) seasons but this difference was not significant at Tigoni.

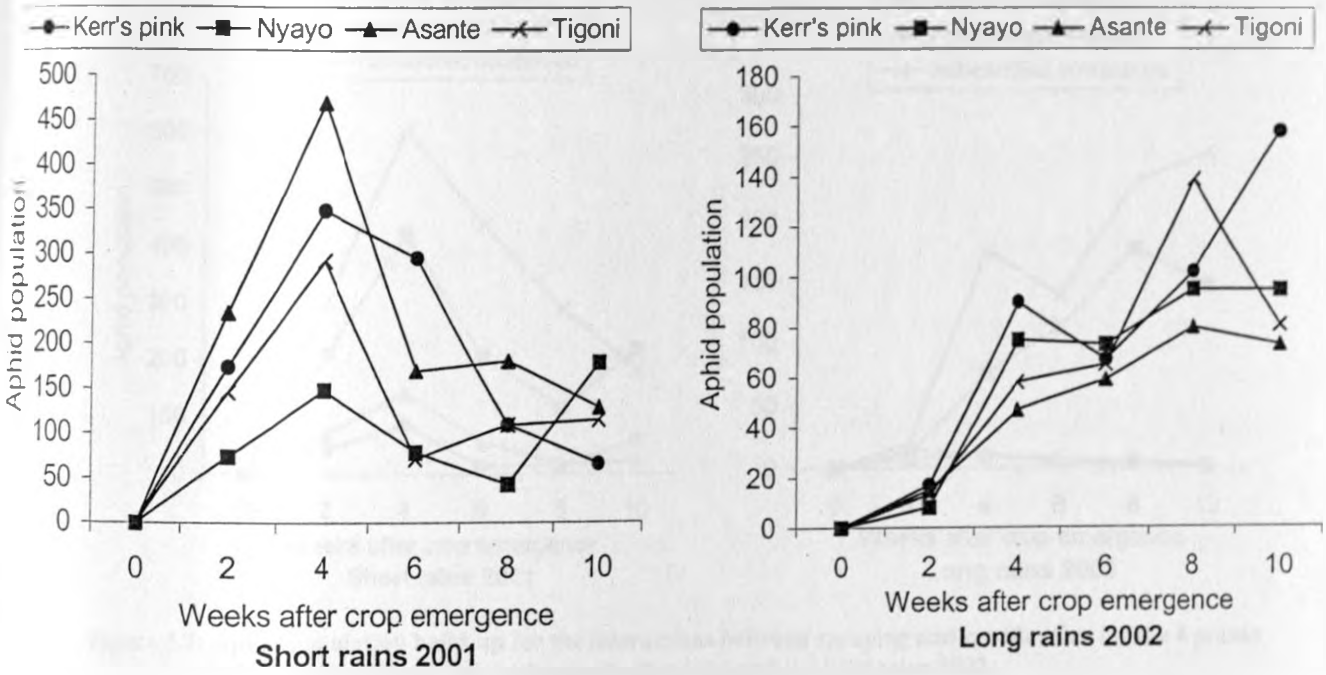


Figure 5.5: Aphid populations on the 4 varieties at the Tigoni site in the short rains 2001 and the long rains 2002 seasons.

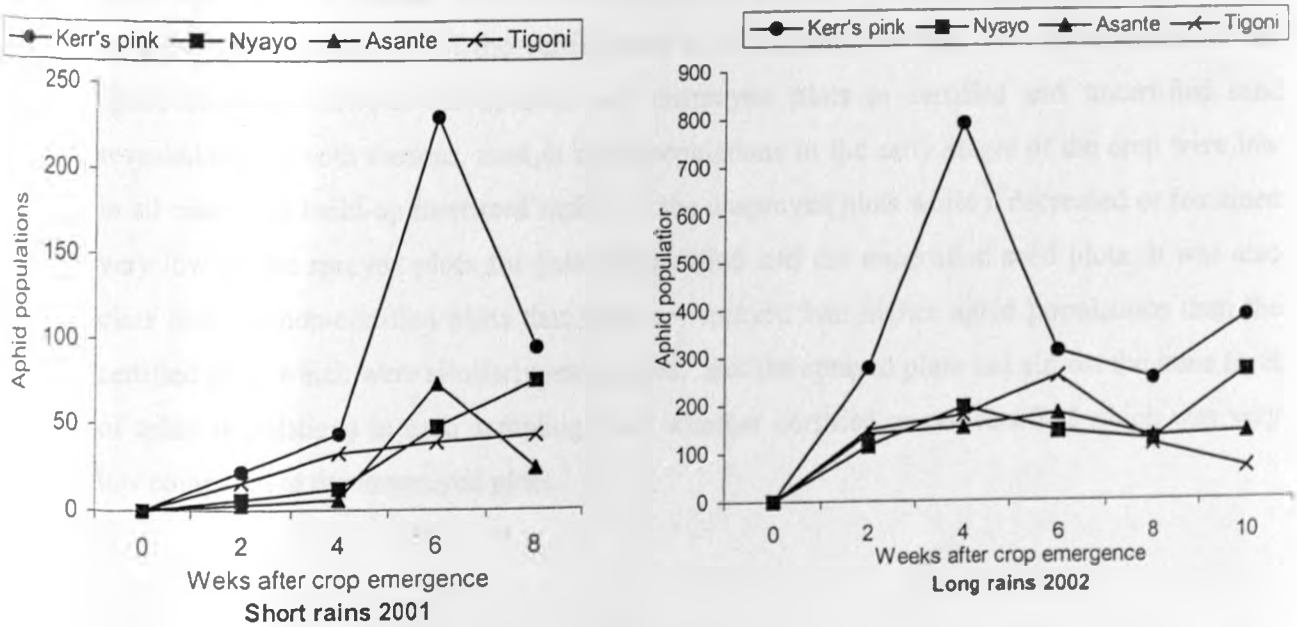


Figure 5.6: Aphid populations on the 4 varieties at the Kabete site in the short rains 2001 and the long rains 2002 seasons.

(iv) **Interactions:** At the Tigoni site the unsprayed plots whether certified or uncertified had higher aphid numbers throughout the 2 seasons than the sprayed plots (Fig 5.7). However, uncertified seed plots maintained much higher aphid numbers than the certified seed plots for similar spraying regime (i.e. sprayed or unsprayed).

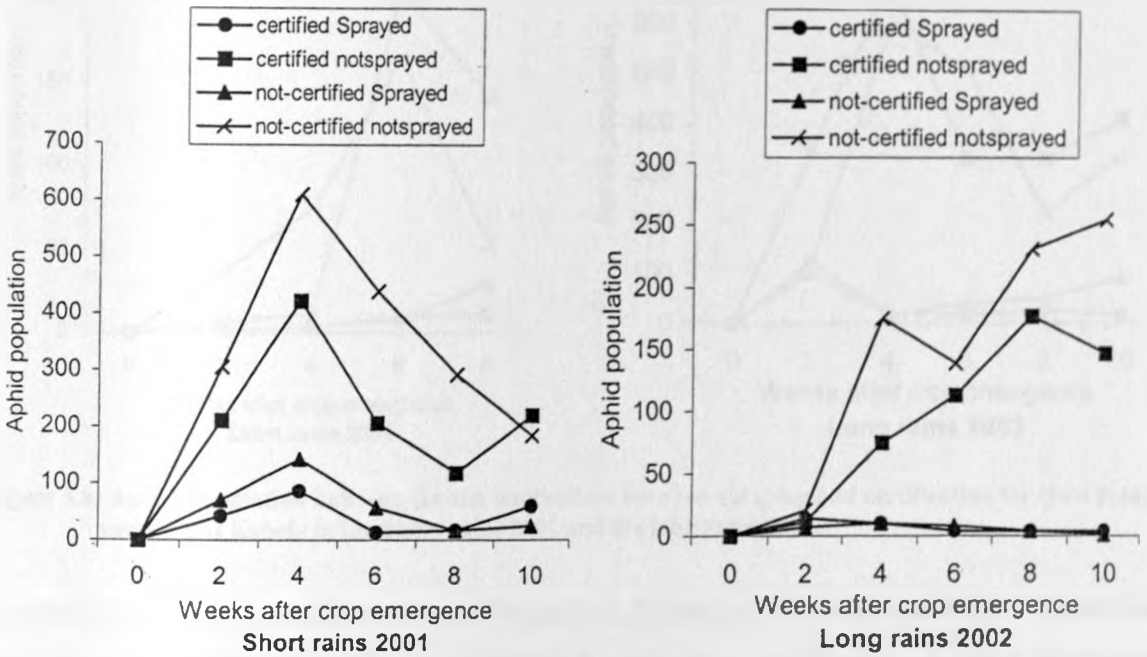


Figure 5.7: Aphid population build up for the interactions between spraying and certification for the 4 potato varieties at the Tigoni site in the short rains 2001 and the long rains 2002.

As in the case of Tigoni, all the unsprayed plots had much higher aphid numbers than the sprayed plots irrespective of the certification at the Kabete site (Fig. 5.8). Comparison of the aphid build-up between the sprayed and unsprayed plots in certified and uncertified seed revealed that in both seasons, though aphid populations in the early stages of the crop were low in all cases, the build-up increased rapidly in the unsprayed plots while it decreased or remained very low in the sprayed plots for both the certified and the uncertified seed plots. It was also clear that the non-certified plots that were not sprayed had higher aphid populations than the certified plots which were similarly not sprayed. But the sprayed plots had almost the same level of aphid populations in each sampling week whether certified or not certified which was very low compared to the unsprayed plots.

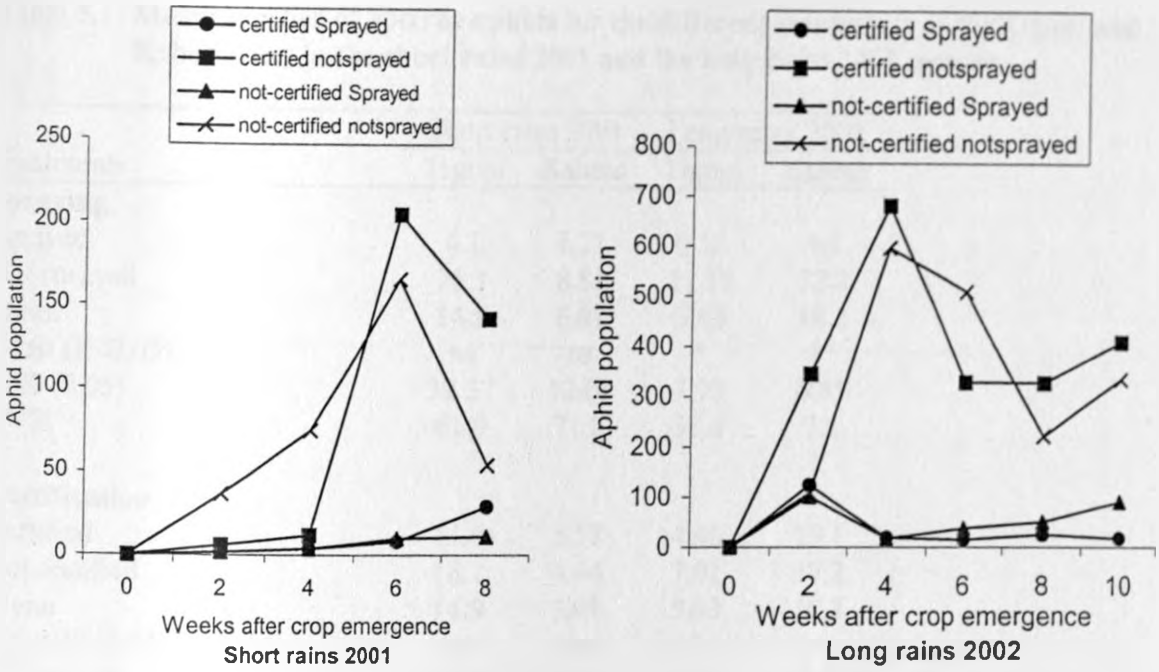


Figure 5.8: Aphid population build-up for the interactions between spraying and certification for the 4 potato varieties at Kabete in the Short rains 2001 and the long rains 2002.

Analysis of the aphid population data at Tigoni and Kabete in both seasons for the 3 factors and their interactions (Table 5.1) showed that there were significant differences in aphid populations between the sprayed and the unsprayed plots both at Tigoni ($P< 0.05$) and Kabete ($P<0.01$) during the long rains 2002 season. The unsprayed plots had higher aphid populations than the sprayed plots. However, the difference in the aphid populations between the sprayings was not significant ($P=0.05$) in the short rains 2001 season at either site. The difference in aphid population numbers between the certified and the uncertified seed plots was only significant during the long rains 2002 at Tigoni ($P<0.05$) but not at Kabete. The uncertified seed plots had more aphids than the certified seed plots. There were no significant differences ($P<0.05$) in aphid population counts between the certifications during the short rains 2001 at either site. The significant differences in aphid population counts between the varieties occurred at Kabete in both the Short rains 2001 ($P<0.05$) and the long rains 2002 ($P<0.001$) seasons. Kerr's pink is the variety that had significantly higher aphid numbers than the other varieties in both seasons at this site. There were no significant differences ($P<0.05$) in aphid population numbers between the different varieties at Tigoni in both seasons. The only interactions that resulted in significant differences in aphid numbers were spraying x certification ($P<0.05$) at Tigoni and spraying x variety ($p<0.001$) at Kabete during the long rains 2002.

Table 5.1: Mean number of apterae aphids for the different treatments at the Tigoni and Kabete sites in the short rains 2001 and the long rains 2002 seasons.

	Short rains 2001		Long rains 2002	
Treatments	Tigoni	Kabete	Tigoni	Kabete
Spraying				
Sprayed	4.1	1.21	0.55	4.1
Not sprayed	25.1	8.81	11.12	32.2
Mean	**14.9**	**5.01**	**5.83**	**18.2**
F-test (P<0.05)	ns	ns	*	**
LSD (0.05)	32.37	12.63	7.95	4.85
CV%	61.9	71.8	38.8	7.6
Certification				
Certified	11.6	5.57	4.66	19.1
Not certified	18.2	4.44	7.01	17.2
Mean	**14.9**	**5.01**	**5.83**	**18.2**
F-test (P<0.05)	ns	ns	*	ns
LSD (0.05)	10.16	7.06	2.03	11.69
CV%	42.6	88	21.7	40.2
Variety				
Kerr's Pink	16.7	10.19	7.07	33.4
Nyayo	9.4	3.73	5.77	14.1
Asante	19	2.89	4.57	12.4
Tigoni	14.4	3.19	5.93	12.8
Mean	**14.9**	**5.01**	**5.83**	**18.2**
F-test (P<0.05)	ns	*	ns	***
LSD (0.05)	16.79	5.49	3.38	7.84
CV%	133.9	130.2	68.9	51.2
Interactions				
Spraying x certification	ns	ns	*	ns
Spraying x variety	ns	ns	ns	***
Variety x certification	ns	ns	ns	ns
Spraying x certification x variety	ns	ns	ns	ns

*, ** and *** denotes significant at P<0.05, P<0.01 and P<0.001 respectively
ns – Not significant at P<0.05

When aphid numbers between Tigoni and Kabete were compared, there was a highly significant difference (P<0.001) in the aphid numbers between the 2 sites in both the short rains 2001 and the long rains 2002 seasons. Tigoni had more aphids in the short rains 2001 season while Kabete had more aphids than Tigoni in the long rains 2002 season. There was also a significant difference (P<0.01) in aphid populations caused by the interaction of spraying x site during the

short rains 2001. The unsprayed plots at Tigoni had significantly higher aphid population numbers than the sprayed plots at both the Tigoni and Kabete sites.

Comparison of the 2 seasons, short rains 2001 and long rains 2002 revealed that there were no significant differences in aphid numbers between the 2 seasons. Interactions that resulted in a significant difference in aphid counts were season x site ($P< 0.001$) and spraying x season x site ($P<0.001$).

5.3.1.2 Aphid species identification

(a) Aphids from **Leaves**

In the short rains 2001 season, there were significant differences in the numbers of *M. euphorbiae* ($P<0.001$) and *A. gossypii* ($P<0.05$) between the 2 sites while there were no significant differences between the 2 sites in the numbers of *M. persicae* and *A. solani* (Table 5.2). Population numbers of *M. euphorbiae* were higher in Kabete than in Tigoni while *A. gossypii* numbers were higher in Tigoni than in Kabete in this season. In the case of the sprayed and unsprayed plots, there was a significant difference in the population numbers of *M. euphorbiae* spp. ($P<0.01$) but no significant difference in the other 3 species. Unsprayed plots had higher populations of *M. euphorbiae* than sprayed plots. These results show that *M. euphorbiae* species was the most affected by spraying in this season. The interaction spraying x site also caused significant differences ($P<0.05$) in the population numbers of *M. euphorbiae* but not of any of the other 3 species. At both sites, *A. gossypii* was the most predominant species followed by *Myzus persicae*, then *M. euphorbiae* and lastly *A. solani* in this short rains season.

In the Long rains 2002 season, there were significant differences in the population of all the 4 species between the 2 sites ($P<0.05$) as well as between the sprayed and unsprayed plots ($P<0.01$). The interaction of site x spraying caused significant differences in the population of all the 4 species ($P<0.05$). A change in species abundance occurred at the Tigoni site during this Long rains 2002 season. *M. euphorbiae* was the most abundant species followed by *A. gossypii, M. persicae* and lastly *A. solani*. The proportions at the Kabete site had *A. gossypii* as the predominant species followed by *M. euphorbiae, M. persicae* and then *A. solani*, which was almost absent.

Table 5.2: Mean number of apterae aphid species on potato leaves sampled at Tigoni and Kabete during the short rains 2001 and the long rains 2002.

	Short rains 2001				Long rains 2002			
Treatments	*M.persicae*	*M.euphorbiae*	*A.gossypii*	*A.Solani*	*M.Persicae*	*M.euphorbiae*	*A.gossypii*	*A.Solani*
Spraying								
Sprayed	5.83	0.86	46	0.39	0.26	1.2	15.1	0.08
Not sprayed	3.53	3.58	49	1	2.64	28.4	95.4	0.53
Mean	**4.68**	**2.22**	**47**	**0.69**	**1.45**	**14.8**	**55.3**	**0.30**
LSD (0.05)	3.29	1.71	70.2	1.16	0.54	9.5	22.59	0.31
F-test (P<0.05)	ns	**	ns	ns	***	***	***	**
Site								
Tigoni	5.54	0.67	83	0.83	1.8	27.1	9.4	0.53
Kabete	3.82	3.78	12	0.56	1.1	2.5	101.2	0.08
Mean	**4.68**	**2.22**	**47**	**0.69**	**1.45**	**14.8**	**55.3**	**0.30**
LSD (0.05)	3.29	1.71	70.2	1.16	0.54	9.5	22.59	0.31
F-test (P<0.05)	ns	***	*	ns	*	***	***	**
Interaction								
Spraying x Site	ns	*	ns	ns	***	***	***	*

*, ** and *** denotes significant at P<0.05, P<0.01 and P<0.001 respectively
ns – Not significant at P<0.05

Comparison of the population of the aphid species on leaves for the 2 seasons revealed that there was a highly significant difference in the mean number of *M. persicae* (P<0.001) and *M. euphorbiae* (P<0.01) between the 2 seasons, but no significant difference in the mean number of the other 2 species, *A. gossypii* and *A. solani* (P=0.05). The mean number of *M. persicae* was higher in the short rains 2001 than in the long rains 2002 season. On the other hand *M. euphorbiae* populations were higher in the long rains 2002 than in the short rains 2001 season. Interactions caused significant differences between all species as follows. *M. euphorbiae* was affected by all interactions, Season x Site (P<0.001), Season x Spraying (P<0.01) and Season x Site x Spraying (P<0.001). *A. gossypii* was also affected by all apart from the season x spraying interaction (P<0.05). *M. persicae* was only affected by the season x site interaction (P<0.01) while *A. solani* was affected only by the 3-way season x site x spraying interaction (P<0.05).

(b) Aphids from **Water traps**

The same species identified on the leaves were also found in the water traps except for *A. solani*, which was completely absent (Table 5.3). The analysis of the data showed that, in the short rains 2001 season, there were no significant differences in the populations of any of the species between the 2 sites and also between the sprayed and the unsprayed plots (P=0.05).

In the long rains 2002 season, there was a significant difference in the population of *M. euphorbiae* (P<0.001) between Tigoni and Kabete. Tigoni had higher populations than Kabete. However, there was no significant difference in the mean numbers of the other 2 species, *A. gossypii* and *M. persicae* between the 2 sites (P=0.05). For the sprayed and unsprayed sides, there were no significant differences in the population of any of the species captured in the water traps (P=0.05). *A. gossypii* was the most predominant species at both sites, followed by *M. euphorbia* and then *M. persicae* in both seasons.

Table 5.3: Mean number of alate aphid species from water traps at Kabete and Tigoni during the short rains 2001 and the long rains 2002.

	Short rains 2001			Long rains 2002		
Treatments	*M.persicae*	*M.euphorbiae*	*A.gossypii*	*M.persicae*	*M.euphorbiae*	*A.gossypii*
Spraying						
Sprayed	0.28	0.5	23.6	0.14	0.65	12.1
Not sprayed	0.56	0.86	20.1	0.13	0.89	13.3
Mean	**0.42**	**0.68**	**21.8**	**0.14**	**0.77**	**12.7**
LSD (0.05)	0.67	0.61	10.53	0.17	0.39	4.86
F-test (P<0.05)	ns	ns	ns	ns	ns	ns
Site						
Tigoni	0.58	0.57	23.1	0.11	1.28	14.4
Kabete	0.25	0.79	20.6	0.16	0.26	10.9
Mean	**0.42**	**0.68**	**21.8**	**0.14**	**0.77**	**12.7**
LSD (0.05)	0.67	0.61	10.53	0.17	0.39	4.86
F-test (P<0.05)	ns	ns	ns	ns	***	ns
Interaction						
Spraying X Site	ns	ns	ns	ns	ns	ns

*** Denotes significant at P<0.001, ns – Not significant at P<0.05

In the comparison of the populations of the aphid species in the water traps for the 2 seasons, the short rains 2001 had higher populations of both *M. persicae and A. gossypii* species than the long rains 2002 season.

5.3.2 VIRUSES

5.3.2.1 Visual virus incidence in different potato varieties of certified and uncertified seed with and without aphid control treatments.

The certified seed plots had a very low score of virus incidence compared to the uncertified plots irrespective of the variety or whether they were sprayed or unsprayed (Table 5.4). Analysis of this data shows that there were highly significant differences ($P<0.001$) in the % visual virus incidence between the certified and uncertified seed plots, and also between the varieties in both seasons and at both sites. Kerr's pink and Nyayo are the varieties that had significantly higher ($P<0.001$) virus incidence than Tigoni and Asante varieties in the short rains 2001 season at both Tigoni and Kabete sites. In the long rains 2002 season, at the Tigoni site, it was only the Tigoni variety that had significantly higher virus incidence than the Nyayo variety ($P<0.05$). There was no significant difference in the visual virus incidence between the other varieties. At the Kabete site in this long rains season, Kerr's pink had significantly higher virus incidence than any of the other 3 varieties while Asante variety had significantly lower virus incidence than any of the other 3 varieties ($P<0.001$). The interaction between certification x variety also resulted in a significant difference ($P< 0.001$), in the visual virus disease incidence (%) at Kabete in the short rains 2001 season. However there was no significant difference in the virus incidence between sprayed and unsprayed plots ($P=0.05$) at any of the 2 sites in both seasons.

Table 5.4: Percent visual virus incidence for the different treatments at Tigoni and Kabete in the Short rains 2001 and the Long rains 2002.

	Short rains 2001		Long rains 2002	
Treatments	Tigoni	Kabete	Tigoni	Kabete
Spraying				
Sprayed	41.3	30.35	57.88	48.9
Not sprayed	44.9	33.93	56.7	49.49
Mean	**43.12**	**32.14**	**57.29**	**49.19**
F-test (P<0.05)	ns	ns	ns	ns
LSD (0.05)	7.11	12.54	6.73	7.51
CV%	4.7	11.1	3.3	4.4
Certification				
Certified	7.8	6.88	26.3	10.94
Not certified	78.44	57.4	88.28	87.44
Mean	**43.12**	**32.14**	**57.29**	**49.19**
F-test (P<0.05)	***	***	***	***
LSD (0.05)	2.79	6.32	3.91	2.56
CV%	4	12.3	4.3	3.3
Variety				
Kerr's Pink	53.96	47.03	58.53	56.07
Nyayo	47.08	39.03	54.44	47.56
Asante	34.17	20.01	55.33	43.09
Tigoni	37.27	22.5	60.85	50.05
Mean	**43.12**	**32.14**	**57.29**	**49.19**
F-test (P<0.05)	***	***	*	***
LSD (0.05)	4.06	8.16	4.61	3.65
CV%	11.2	30.2	9.6	8.8
Interactions				
Spraying x certification	ns	ns	ns	ns
Spraying x variety	ns	ns	ns	ns
Certification x variety	ns	***	ns	ns
Spraying x certification x variety	ns	ns	ns	ns

* and *** denotes significant at P<0.05 and P<0.001 respectively
ns – Not significant at P<0.05

Comparison of the average virus incidence for Tigoni and Kabete during the short rains 2001 season showed that Kabete had generally lower virus incidence compared to the corresponding plots and variety at Tigoni. In the Long rains, 2002 Season, comparison of the virus incidence at the 2 sites also revealed a similar trend that the virus incidence at Kabete was lower than in Tigoni in most corresponding plots.

5.3.2.2 Serological identification of the Viruses (ELISA Results)

The mean percentage of samples that tested positive for the Potato virus 'S', Potato leaf roll virus and Potato Virus Y in leaves and in tubers at the Tigoni and Kabete sites during the long rains 2002 are shown in tables 5.5 and 5.6 respectively.

Table 5.5: Percentage of samples that tested positive for the Potato Virus S (PVS), Potato leaf roll virus (PLRV) and the Potato Virus Y (PVY) at Tigoni during the Long rains 2002.

	PVS		PLRV		PVY	
Treatments	Leaves	Tubers	Leaves	Tubers	Leaves	Tubers
Spraying						
Sprayed	70.83	77.08	54.17	2.08	27.08	0.00
Not sprayed	72.92	77.08	47.92	8.34	27.08	2.08
Mean	**71.90**	**77.10**	**51.00**	**5.21**	**27.10**	**1.04**
F-test (P<0.05)	ns	ns	ns	ns	ns	ns
LSD (0.05)	14.06	21.60	21.80	6.72	20.60	4.16
Certification						
Certified	56.25	70.83	43.75	2.08	16.67	2.08
Not certified	87.50	83.33	58.34	8.34	37.50	0.00
Mean	**71.90**	**77.10**	**51.00**	**5.21**	**27.10**	**1.04**
F-test (P<0.05)	***	ns	ns	ns	ns	ns
LSD (0.05)	14.06	21.60	21.80	6.72	20.60	4.16
Variety						
Kerr's Pink	37.50	66.67	75.00	7.50	45.83	0.00
Nyayo	62.50	50.00	37.25	0.00	62.50	4.17
Asante	91.67	91.67	16.67	8.34	0.00	0.00
Tigoni	95.83	100.00	75.00	4.17	0.00	0.00
Mean	**71.90**	**77.10**	**51.00**	**5.21**	**27.10**	**1.04**
F-test (P<0.05)	***	*	**	ns	**	ns
LSD (0.05)	19.90	30.60	30.80	9.50	29.20	5.90

*, ** and *** denotes significant at P<0.05, P<0.01 and P<0.001 respectively
ns – Not significant at P<0.05

Table 5.6: Percentage of samples that tested positive for the Potato Virus S (PVS), Potato leaf roll virus (PLRV), Potato Virus Y (PVY) and Potato Virus X (PVX) at Kabete during the Long rains 2002.

	PVS		PLRV		PVY		PVX	
Treatments	Leaves	Tubers	Leaves	Tubers	Leaves	Tubers	Leaves	Tubers
Spraying								
Sprayed	83.33	87.50	52.08	33.33	35.42	45.83	18.75	16.67
Not sprayed	85.42	95.83	52.09	20.83	39.58	50.00	37.50	4.17
Mean	**84.40**	**91.70**	**52.10**	**27.08**	**37.50**	**47.90**	**28.12**	**10.42**
F-test (P<0.05)	ns	ns	ns	*	ns	ns	*	*
LSD (0.05)	15.48	12.36	25.20	9.50	27.60	12.64	15.48	10.54
Certification								
Certified	75.00	87.50	37.50	22.92	25.00	43.75	33.33	8.33
Not certified	93.75	95.83	66.67	31.25	50.00	52.08	22.92	12.50
Mean	**84.40**	**91.70**	**52.10**	**27.08**	**37.50**	**47.90**	**28.12**	**10.42**
F-test (P<0.05)	*	ns	*	ns	ns	ns	ns	ns
LSD (0.05)	15.48	12.36	25.20	9.50	27.60	12.64	15.48	10.54
Variety								
Kerr's Pink	75.00	95.83	79.17	29.17	75.00	50.00	20.83	8.33
Nyayo	62.50	70.83	12.50	25.00	62.50	91.67	37.50	20.83
Asante	100.00	100.00	37.50	20.84	0.00	16.67	8.33	0.00
Tigoni	100.00	100.00	79.17	33.33	12.50	33.33	45.83	12.50
Mean	**84.40**	**91.70**	**52.10**	**27.08**	**37.50**	**47.90**	**28.12**	**10.42**
F-test (P<0.05)	*	*	**	ns	**	***	*	ns
LSD (0.05)	21.80	17.48	34.96	13.44	39.00	17.88	21.8	14.9

*, ** and *** denotes significant at P<0.05, P<0.01 and P<0.001 respectively
ns – Not significant at P<0.05

1. Potato Virus S (PVS)

Asante and Tigoni varieties had higher percentages of samples infected with PVS virus than Kerr's Pink and Nyayo in leaves and also in tubers at both Tigoni and Kabete sites. Certified seed had also lower percent PVS than the uncertified seed in leaves and also in tubers at both sites. Analysis of these results revealed that there were no significant differences between the sprayed and the unsprayed plots in percent PVS virus present in leaves and also in tubers at both Tigoni and Kabete sites (P=0.05). However, there was a highly significant difference in the % PVS present in leaves between the certified and the uncertified plots and also between the different varieties at Tigoni (P=0.001) and also at Kabete (P<0.05). There was a significant difference (P<0.05) between different varieties but not between the certified and the uncertified seed plots in % PVS present in Tubers at both Sites.

2. Potato leaf roll virus (PLRV)

Kerr's Pink and Tigoni varieties had higher percentage of PLRV than Nyayo and Asante. The difference in PLRV percentages was significant between the leaf samples ($P<0.01$) but not the tuber samples ($P=0.05$) at both Tigoni and Kabete sites. The percentage of PLRV was not significantly different between the sprayed and unsprayed plots in leaves at both sites. There was a significant difference ($P<0.05$) between the sprayed and unsprayed plots in percent samples infected with PLRV in tubers at Kabete but not at Tigoni. The percent PLRV was not significantly different between the certified and the uncertified seed plots at both sites ($P=0.05$).

3. Potato Virus Y (PVY)

PVY was mostly found in Kerr's Pink and Nyayo varieties. There was no PVY in Asante and Tigoni varieties at the Tigoni site either in leaves or in tuber samples. PVY was also much lower in the same varieties at the Kabete site. There were significant differences between the different varieties in percent PVY in leaves ($P<0.01$) at both Tigoni and Kabete sites. There was also a highly significant difference between varieties in the % PVY in tubers at the Kabete site ($P<0.001$) but no significant difference in the percentage of PVY content in tubers at the Tigoni site. Spraying and seed certification did not result in any significant difference in the percent of PVY in leaves and in tubers at either Tigoni or Kabete sites.

4. Potato Virus X (PVX)

The PVX virus was not detected at the Tigoni site either in leaves or in tubers. At the Kabete site however, Asante variety had a much lower percent of this virus than the other three varieties, Tigoni, Nyayo and Kerr's pink. There was a significant difference between the varieties in the percentage of PVX detected in leaves ($P<0.05$) but not in tubers. There was also a significant difference ($P<0.05$) between the sprayed and the unsprayed plots in the percentage of PVX present in leaves and also in tubers. However, there was no significant difference between the certified and the uncertified seed plots in the percentage of PVX present in leaves or in tubers. There was generally more PVX in leaves than in Tubers.

5.3.3 YIELD LOSS ASSESSMENT DUE TO APHID INFESTATION AND VIRUS INFECTION IN SEED POTATOES

5.3.3.1 Assessment of yields in different potato varieties for certified and uncertified seed, with and without aphid control treatments.

In general, yields from certified seeds were always higher than yields from the non-certified seed plots in the 2 seasons at both sites. At the Tigoni site (Table 5.7), there were no significant differences between the sprayed and non-sprayed plots in the yield of any tuber grades, ware, seed, or rejects during the short rains 2001 and the long rains 2002 seasons. There was however a highly significant difference ($P<0.001$) between certified and uncertified seed plots in the yield of ware potatoes in the short rains 2001 but not in the long rains 2002 season. Certified seed plots had a higher yield of ware potatoes than the uncertified seed plots. Highly significant differences ($P<0.001$) also occurred between the varieties in the yield of all potato grades, ware, seed and rejects in both seasons. Kerr's pink variety had the lowest yields followed by Nyayo while Tigoni and Asante varieties had the highest yields. Interactions that caused significant differences in tuber yields were variety x certification for ware potatoes ($P<0.01$) and, spraying x certification x variety for rejects ($P<0.05$) in the short rains 2001 season.

At Kabete (Table 5.8), certified plots yields were also always higher than the yields of the uncertified plots, and yields from the sprayed plots were generally higher than those from unsprayed plots. Kerr's Pink had lower yields than the other varieties for corresponding plot treatments followed by Nyayo while Tigoni and Asante had the highest yields at Kabete during this short rains 2001 and the long rains 2002 seasons as was the case at the Tigoni site. From the analysis of this yield data, there were significant differences between the sprayed and the unsprayed plots in the yield of ware and the reject potatoes ($P<0.01$) in the short rains 2001 but not in the long rains 2002 seasons. The sprayed plots had more ware potato than the unsprayed plots, while the unsprayed plots had significantly more rejects than the sprayed plots. As for the seed certification, there was a significant difference between the certified and the uncertified seed in yield of the rejects ($P<0.01$) during the short rains 2001 season and also in the yields of the ware potatoes in the long rains 2002. The other tuber grades were not significantly different in their yields in the respective seasons. However, the certified seed yields were always higher than the uncertified seed yields for all tuber grades (Ware, seed and rejects). Between the varieties, there were highly significant differences in the tuber yield ($P<0.001$) for all the tuber grades in both seasons apart from the seed grade whose yield was not significantly different

between the varieties in the short rains 2001 season. The interaction between spraying x certification caused significant differences in the yields of rejects (P<0.01) during the short rains 2001 and ware potatoes (P<0.05) during the long rains 2002 season. Certification x variety interaction caused significant differences in the tuber yields of seed potatoes (P<0.01) during the short rains 2001 and ware potatoes (P<0.05) and rejects (P<0.001) during the long rains 2002.

Table 5.7: Mean Potato tuber yields (tons/ha) at Tigoni in the short rains 2001 and the long rains 2002 seasons.

	Short rains 2001			Long rains 2002		
Treatments	Ware	Seed	Rejects	Ware	Seed	Rejects
Spraying						
Sprayed	10.16	6.45	1.09	2.31	3	0.3
Not sprayed	8.67	6.45	1.1	2.5	3.17	0.36
Mean	**9.42**	**6.45**	**1.09**	**2.41**	**3.08**	**0.84**
F-test (P<0.05)	ns	ns	ns	ns	ns	ns
LSD (0.05)	4.32	1.90	1.21	2.21	0.8	0.23
CV%	13.1	8.4	31.5	26.1	7.4	19.4
Certification						
Certified	12.05	6.28	0.99	2.72	3.48	0.36
Not certified	6.78	6.61	1.2	2.1	2.68	0.3
Mean	**9.42**	**6.45**	**1.09**	**2.41**	**3.08**	**0.84**
F-test (P<0.05)	***	ns	ns	ns	ns	ns
LSD (0.05)	1.03	1.34	0.36	0.72	0.95	0.15
CV%	13.1	13	20.7	18.5	19.2	27.8
Variety						
Kerr's Pink	2.77	3.91	0.81	0.17	0.72	0.28
Nyayo	8.9	6.32	1.24	2.54	4.58	0.57
Asante	12.93	7.48	0.74	3.86	3.06	0.22
Tigoni	13.07	8.07	1.58	3.06	3.97	0.26
Mean	**9.42**	**6.45**	**1.09**	**2.41**	**3.08**	**0.84**
F-test (P<0.05)	***	***	***	***	***	*
LSD (0.05)	1.63	1.09	0.42	0.93	0.91	0.22
CV%	20.5	19.5	45.3	46	35	79.3
Interactions						
Spraying x certification	ns	ns	ns	ns	ns	ns
Spraying x variety	ns	ns	ns	ns	ns	ns
Variety x certification	**	ns	ns	ns	ns	ns
Spraying x certification x variety	ns	ns	*	ns	ns	ns

*, ** and *** denotes significant at P<0.05, P<0.01 and P<0.001 respectively
ns – Not significant at P<0.05

Table 5.8: Mean Potato tuber yields (tons/ha) at Kabete during the short rains 2001 and the long rains 2002 seasons.

	Short rains 2001			Long rains 2002		
Treatments	Ware	Seed	Rejects	Ware	Seed	Rejects
Spraying						
Sprayed	3.81	8.29	3.69	3.22	4.22	1.03
Not sprayed	1.94	5.48	6.94	3.25	4.2	0.8
Mean	**2.88**	**6.89**	**5.32**	**3.23**	**4.21**	**0.92**
F-test (P<0.05)	**	ns	**	ns	ns	ns
LSD (0.05)	0.66	2.86	0.82	2.18	0.7	0.73
CV%	6.6	11.8	4.4	19.2	4.7	22.7
Certification						
Certified	3.28	7.43	5.86	4.09	4.37	0.96
Not certified	2.47	6.34	4.77	2.37	4.05	0.87
Mean	**2.88**	**6.89**	**5.32**	**3.23**	**4.21**	**0.92**
F-test (P<0.05)	ns	ns	**	***	ns	ns
LSD (0.05)	1.42	2.62	0.62	0.44	0.68	0.60
CV%	31	23.8	7.2	8.5	10.1	40.6
Variety						
Kerr's Pink	1.31	5.79	3.27	1.09	1.89	0.47
Nyayo	2.36	7.34	6.03	2.93	5.21	1.53
Asante	4.76	7.18	5.72	5.13	4.42	0.68
Tigoni	3.08	7.23	6.25	3.77	5.31	0.97
Mean	**2.88**	**6.89**	**5.32**	**3.23**	**4.21**	**0.92**
F-test (P<0.05)	***	ns	**	***	***	***
LSD (0.05)	1.26	1.26	1.49	0.90	0.93	0.40
CV%	51.9	21.7	33.3	32.9	26.3	51.4
Interactions						
Spraying x certification	ns	ns	**	*	ns	ns
Spraying x variety	ns	ns	ns	ns	ns	ns
Variety x certification	ns	**	ns	*	ns	***
Spraying x certification x variety	ns	ns	ns	ns	ns	ns

*, ** and *** denotes significant at P<0.05, P<0.01 and P<0.001 respectively
ns – Not significant at P<0.05

The short rains 2001 season had higher yields than the long rains 2002 season in seed and rejects potato tuber grades. Ware potato yields were higher in the long rains 2002 than in the short rains 2001 season. Overall, Kabete had higher total yields than Tigoni. For the respective tuber grades, Kabete had higher yields for the seed and reject potato grades but Tigoni seemed to have larger tubers and therefore ware grade potato yields were higher in Tigoni than in Kabete.

5.3.3.2 RELATIONSHIP BETWEEN THE APHID POPULATIONS, VIRUS INCIDENCE AND YIELDS OF POTATO IN THE DIFFERENT TREATMENTS

There was a highly significant relationship between the virus incidence and yields of the potato varieties both at Tigoni ($P<0.01$) and Kabete ($P<0.001$). This relationship was such that as the virus incidence increased, the yields decreased significantly at both sites (Fig. 5.9 and 5.10).

There was no significant relationship ($P=0.05$) between aphid populations and yields at the Tigoni site (Fig.5.11). However there was a highly significant relationship ($P<0.001$) between aphid populations and yields at the Kabete experimental site. This relationship was such that as the population of aphids increased, the yield of potatoes decreased significantly (Fig. 5.12).

There was no significant relationship between aphid populations and virus incidence at either Tigoni or Kabete sites ($P=0.05$). However, at both the Tigoni and Kabete sites, as the populations of aphids increased, the virus incidence also increased (Fig. 5.13 and 5.14).

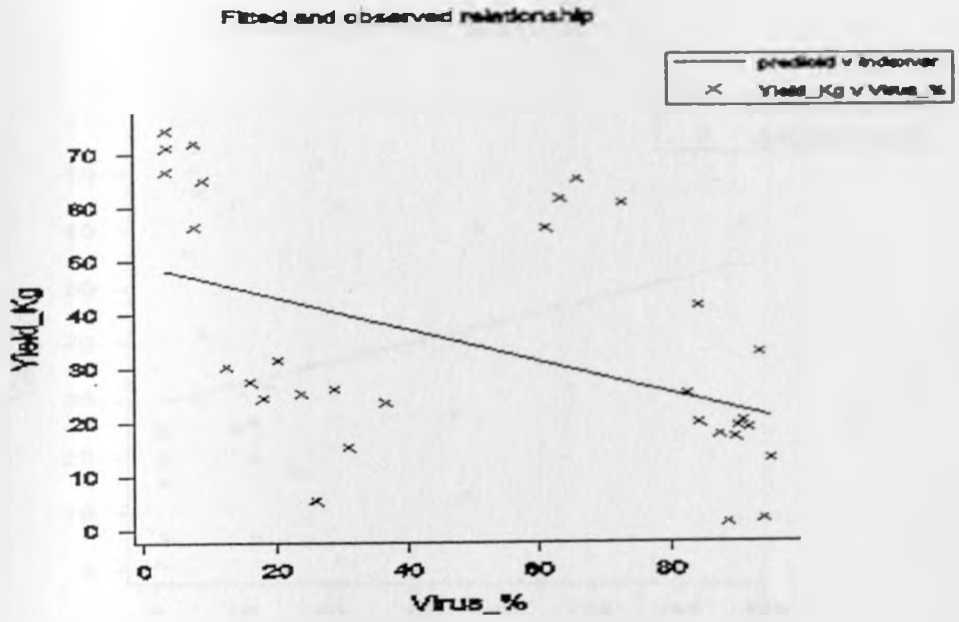


Figure 5.9: Relationship between Potato Virus incidence and the Yields of Potatoes at Tigoni during the short rains 2001 and the long rains 2002

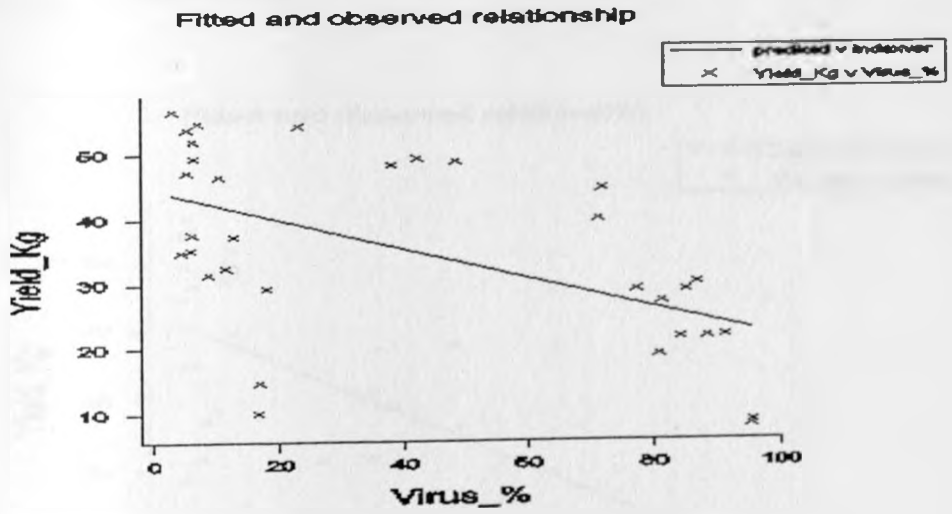


Figure 5.10: Relationship between Potato Virus incidence and the Yields of Potatoes at Kabete during the short rains 2001 and the long rains 2002.

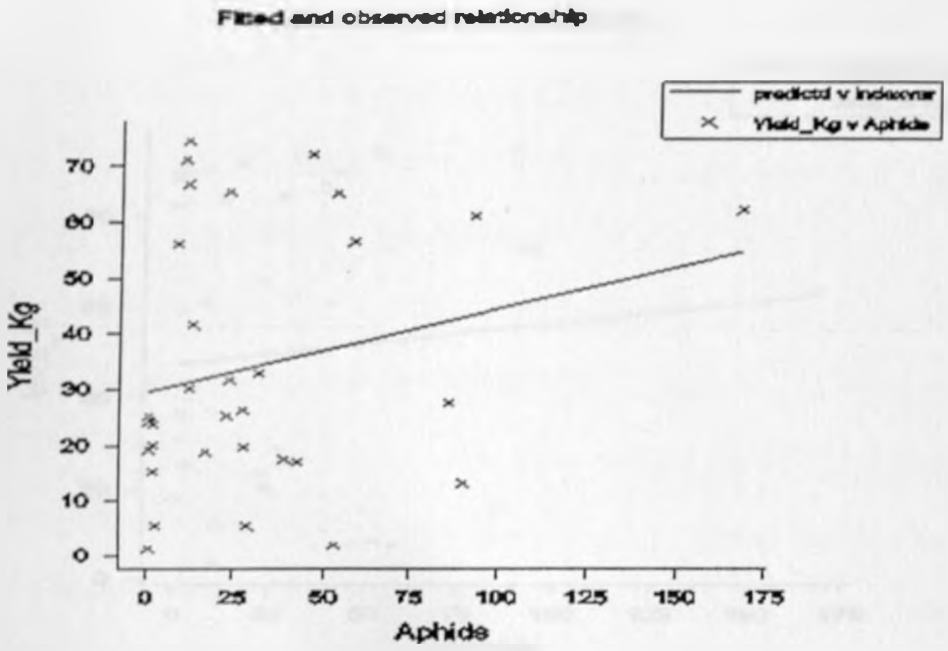


Figure 5.11: Relationship between Potato Aphids populations and the Yields of potatoes at Tigoni during the short rains 2001 and the long rains 2002.

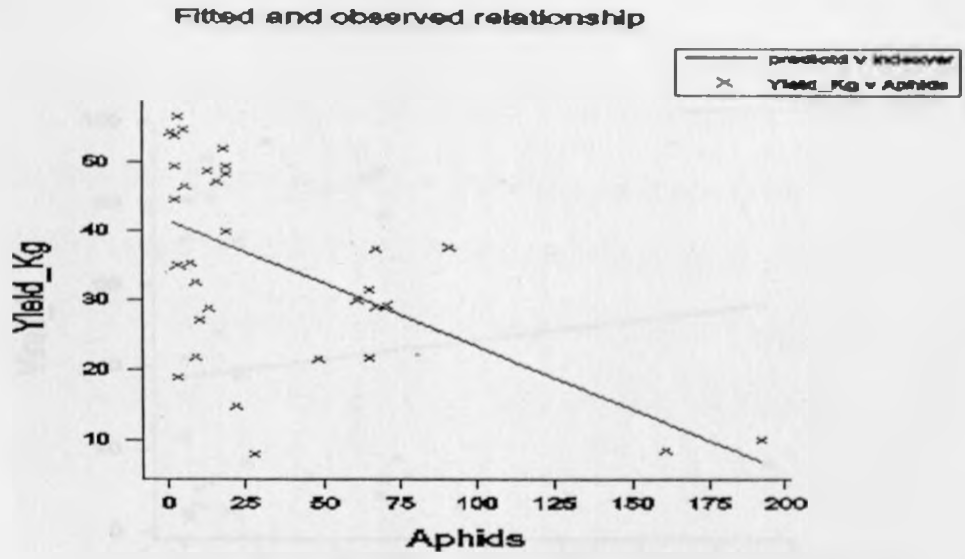


Figure 5.12: Relationship between Potato Aphids populations and the Yields of potatoes at Kabete during the short rains 2001 and the long rains 2002.

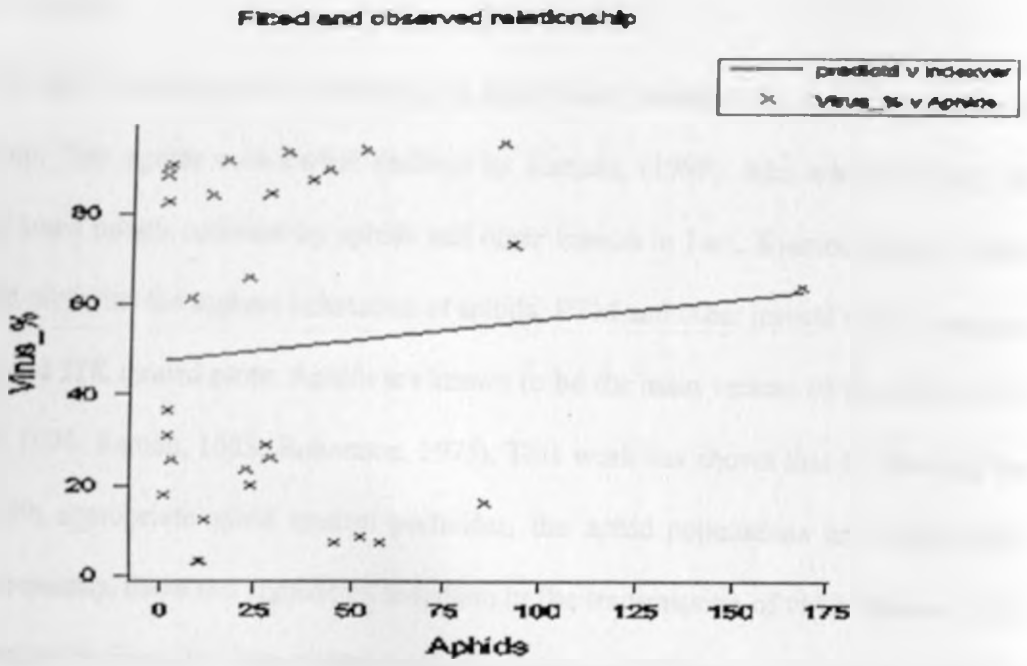


Figure 5.13: Relationship between Aphid populations and Virus incidence on Potato at Tigoni during the short rains 2001 and the long rains 2002.

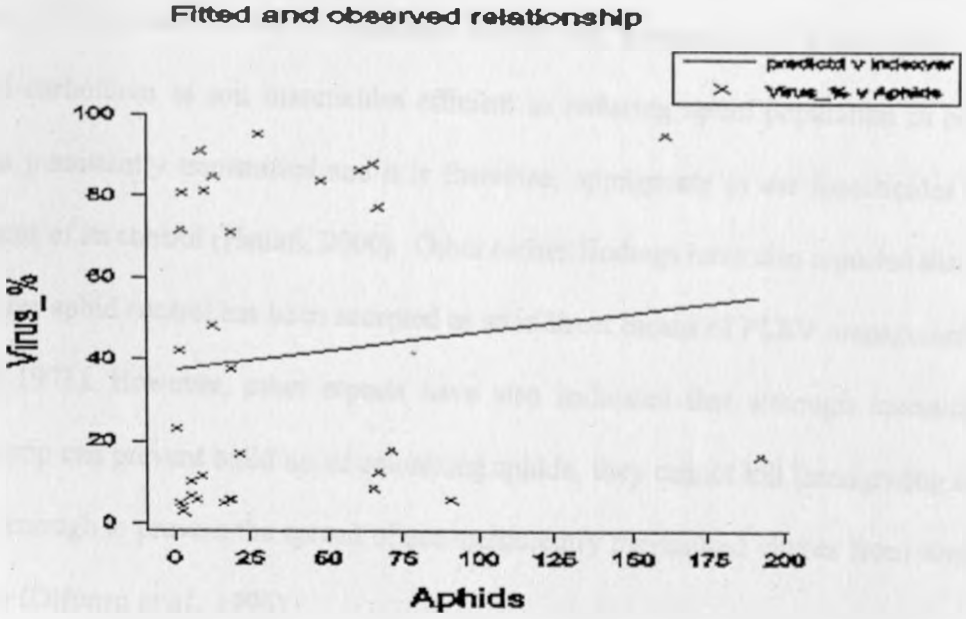


Figure 5.14: Relationship between Aphid populations and Virus incidence on Potato at Kabete during the short rains 2001 and the long rains 2002.

5.4 DISCUSSION

Results of the aphid sampling show that spraying significantly reduced the aphid population in the potato crop. This agrees with earlier findings by Kariuki, (1999), who while studying the infestation of some potato cultivars by aphids and other insects in Lari, Kiambu district, found that unsprayed plots had the highest infestation of aphids, PTM and other insects when compared to insecticide and ITK treated plots. Aphids are known to be the main vectors of the potato virus diseases (CIP, 1996; Raman, 1985; Robertson, 1975). This work has shown that by spraying the potato crop with appropriate aphid control pesticides, the aphid populations are significantly reduced. Consequently, there is a significant reduction in the transmission of virus diseases. This agrees with earlier findings that insecticides use in the control of aphids is an indirect control of potato viruses such as PLRV and PVY (Woodford and Gordon, 1990). Radcliffe (1982) observed that insecticides applied in furrows at planting or side dressed at the time of emergence are more effective in suppressing aphid populations and also minimize virus spread in potato fields. Nderitu (1983) found use of Oxydemeton methyl and dimethoate as foliar sprays and disulfalton and carbofuran as soil insecticides efficient in reducing aphid population in potato plots. PLRV is persistently transmitted and it is therefore, appropriate to use insecticides as a major component of its control (Hanafi, 2000). Other earlier findings have also reported that use of insecticides for aphid control has been accepted as an indirect means of PLRV management in potatoes (Till, 1971). However, other reports have also indicated that although insecticides applied to the crop can prevent build up of colonizing aphids, they cannot kill immigrating alate aphids quickly enough to prevent the spread of non-persistently transmitted viruses from sources outside the crop (Difonzo *et al.*, 1996).

Visual virus incidence and serological virus assay (ELISA) results show that uncertified seed had much higher percentage of visual virus incidence than certified seed. ELISA results also revealed that all the 4 viruses under investigation, i.e. PVS, PLRV, PVY and PVX were

present in significantly higher percentage of samples in the uncertified potato plots than in the certified plots.

This shows that planting certified seed greatly reduces the virus incidence in potato plants as well as the different types of viruses that infect the potato crop. The viruses that are especially known to be transmitted by aphids and infected tubers PLRV and PVY (Raman, 1985) were especially lower in the certified seed than in the uncertified seed. This shows that aphid control, which is strictly practiced in certified seed production, greatly helps in the reduction of the aphid-transmitted viruses. Use of certified seed therefore plays a big role in preventing virus spread from seed, which would then be transmitted by aphids from infected plants to other healthy plants. Earlier findings have also indicated that, there is need to disseminate information on certified seeds for wider adoption (Walingo *et al.*, 2002). It has been reported that certified seed is expensive and sometimes unavailable (Ajanga, 1993) and that collapse of seed certification program in the country may have contributed to the high virus incidence in Kenya (Walingo *et al.*, 2002). Abdalla and Elshafie (1983) and Ateka (1999) found that most farmers either used seeds saved from previous crop or seed simply purchased from the local markets.

Aphids are known to cause direct injury to potato and also transmit viral diseases that depress yields by as much as 80% (Goffinet, 1982). Results of the yield loss assessment between certified and uncertified potato seed showed that there was a highly significant reduction in the potato yields in the uncertified seed plots compared to the certified seed plots. This shows that seed certification, (which ensures that proper aphid control and virus management measures are practiced), plays a major role in maintaining high yields in the potato crop. There is therefore a great danger of lowering potato yields to uneconomical levels by continued use of uncertified seed by farmers. Earlier reports have indicated that quality of seed potato tubers is the most important yield-determining factor and also a major constraint in many potato-growing developing countries (Struik and Wiersema, 1999).

Analysis of the relationship between the aphid populations, virus incidence and yields revealed that there was a significant reduction in yields with increase in virus incidence. There was also a significant decrease in potato yields with increase in aphid populations at the Kabete site, which is at a lower altitude than Tigoni site hence more active aphid activity in the transmission of the potato viruses. It has previously been reported that high altitude affects the activity of aphids due to limited flight (Bertschinger, 1992). In Tigoni, there was no significant difference in yields due to aphid populations hence it might not have been economical to spray ware potatoes for aphid control. These findings tally with the findings of the research at Lari area where it was found that it would be uneconomical to spray ware potatoes against aphids in that region since yields were not affected much by the presence of aphids (Kariuki, 1999). This finding is also similar to that of Nderitu and Mueke (1986) who found that although some 3 varieties, Annet, Kerr's pink and Desiree had a high number of aphids, they also had high yields. They concluded that the aphid population was probably not high enough to affect the yields significantly. Fletcher *et al.*, (2002) working with several varieties found that primary infection by PLRV from outside a field had little effect on yields of cv. Desiree, Red Rascal and Shepody. However, since farmers also use some ware potatoes as seed it is still advisable to spray both ware and seed potatoes in these areas to reduce incidences of latent virus disease infections, which would later be transmitted by the seed to the next crop. Though there was no significant relationship between the aphid populations and the virus incidence, it was clear from the graphs of regression analysis at both sites (Tigoni and Kabete) that, as the aphid population increased, the virus incidence also increased at both sites.

This shows that, with more time, there is a possibility of a significant increase in the virus incidence with increase in aphid activity. This would then lead to a significant decrease in the potato yields due to the increased virus incidence. These results therefore indicate a relationship between the aphid populations, virus incidence and seed degeneration leading to serious yield

loss in the potato crop. Control of aphids to reduce the virus disease spread is therefore necessary if virus free potato seed production is to be maintained for sustained high yield levels of ware potatoes in this region.

Another important observation from this study is the finding that the different potato varieties had significantly different percentage levels of infection by different viruses. Tigoni and Asante varieties were significantly more susceptible to PVS infection than Kerr's pink and Nyayo varieties while Kerr's pink and Tigoni were significantly more susceptible to PLRV than Asante and Nyayo varieties. On the other hand, Kerr's pink and Nyayo were significantly more susceptible to PVY than Asante and Tigoni while only the Asante variety exhibited significantly lower susceptibility to PVX than the other 3 varieties (Tigoni, Nyayo and Kerr's pink). These results show that some potato varieties are more tolerant to some virus infections than other varieties. In this study, Asante variety exhibited most tolerance by being less susceptible to all the viruses (PLRV, PVY and PVX) apart from one virus (PVS). On the other hand Kerr's pink variety was susceptible to all the viruses (PLRV, PVY and PVX) and only slightly less susceptible to PVS than Tigoni and Asante. It was also observed that Nyayo was the second most tolerant, as it was tolerant to two viruses (PVS and PLRV) and susceptible to two (PVY and PVX). Tigoni could be ranked as the second most susceptible variety after Kerr's Pink as it was susceptible to three viruses (PVS, PLRV and PVX) and significantly tolerant to only one virus PVY. Significant differences also occurred in aphid populations between the varieties at Kabete in both the short rains and the long rains seasons. Kerr's pink is the variety that had significantly higher aphid population than the other varieties in both seasons. Nderitu (1983) also reported differential infestation of aphids in the field. Nderitu and Mueke (1986) found that vigorous growth during the long rains season clearly brought out varietal differences in aphid infestation. They reported that Annet, Kerr's pink and Desiree were the most highly infested potato cultivars, while Roslin Tana was the least infested cultivar.

These results show that, apart from the use of aphid control measures and certified seed to prevent virus spread, resistant varieties to aphid infestation and virus infection could be identified and used to lower virus infection in seed potatoes. In this study the 4 varieties could be ranked in order of resistance to viruses as 1. Asante, 2. Nyayo 3. Tigoni and 4. Kerr's pink. Aphid population study had also shown that Kerr's pink was the most susceptible variety to aphid infestation with aphid populations significantly higher than in the other 3 varieties (Tigoni Asante and Nyayo). This variety also had significantly lower yields than any of the other 3 varieties. Seed farmers should therefore be discouraged from growing such a variety and encouraged to grow the more resistant and higher yielding varieties like Asante then Nyayo and Tigoni. Earlier studies have also found that, in the field, different potato cultivars display different levels of aphid infestation (Tayler, 1962; Nderitu and Mueke, 1986; Were, 1996). Varying levels of resistance to aphid infestation have also been reported in wild tuber bearing *Solanum* species (Radcliffe and Laner, 1970,1971). Sams *et. al.* (1976) also identified green peach resistance in *Solanum* progenies, while Mndolwa *et. al.* (1984) observed greater resistance in *Solanum tuberosum* gp.*andigena* and hybrids than in gp. *tuberosum* cultivars. Nderitu and Mueke (1988) also reported some resistance in a local cultivar, Roslin Tana in Kenya. However more studies are required in this area of aphids and Potato viruses' resistance, as not much has been documented in Kenya.

CHAPTER SIX

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL DISCUSSION

From the results of these studies, it has become clear that clean potato seed production is important for subsequent good yields of ware and seed potatoes by the farmers. Use of uncertified seed has been shown to result in significantly higher incidences of virus diseases. This then leads to a significant reduction in the yields of the infected potatoes. Field surveys and on-farm monitoring are useful in assessing the actual situation in the field under farmer management practices. The results of the field situation compared with the results of on-station experiments give a good insight of how the farmer management practices affect the quality and the quantity of their crop yields.

In this study, there has been a lot of agreement in the results of the three areas of study in this thesis. The field survey in farmers' fields at Tigoni, Njabini and Molo revealed that virus incidence was high in farmers' fields where farmers recycled their own seed and no certified seed was used. Aphid populations were also high in farmers' fields where no control measures for aphids were used. There were more aphids in the lower altitude zones of the survey areas (Tigoni) than in the higher altitude zones (Njabini and Molo). The yield in the surveyed farms where certified seed was used was also much higher than in farms where no certified seed was used. This agrees with previous findings that quality of seed potato tubers is the most important yield-determining factor and also a major constraint in many potato-growing developing countries (Struik and Wiersema, 1999). The significance of these results is that farmers who plant virus infected uncertified seed and do not practice aphid control measures end up spreading the virus diseases more and more in their potato crop. This leads to the ever decreasing yields of their potato crop. This has the wider implication of continued reduction in national seed potato and ware potato yields in the country. Since potato production contributes tremendously to food security in Kenya (Anon, 2002), food security in the country is therefore greatly and negatively affected.

The main aphids identified were *A. gossypii* followed by *M. euphorbiae* then *M. persicae* and lastly *A. solani*. This agreed with previous findings that in Kenya *Myzus persicae*, *M. euphorbiae*, *A. solani* and *A. gossypii* are the major aphid species that infest potatoes and transmit viruses (Robertson, 1975; Nderitu and Mueke, 1986; Mbula, 1992; Were, 1996). For the viruses in this survey, PVS was the most encountered virus followed by PLRV, PVY and lastly PVX.

These results agreed with those of the on-farm monitoring where the aphid species and the viruses identified, followed the same order. It was also clear that farms where aphid control measures were applied had much lower aphid numbers than where no control was practiced. Virus incidence was also lower where certified seed was used and where virus control measures like roguing was practiced than where no certified seed or virus control measures were practiced. This agrees with the findings in the field survey study where farmers using certified seed had lower virus incidence.

The results of the on-station experiments also agreed with those of the other 2 studies, field survey and on-farm monitoring. The most encountered aphid species in the on-station experiments were *Aphis gossypii*, followed by *M. persicae*, *M. euphorbiae* then *A. solani* during the short rains season. This was the same order found at the Tigoni site during the field survey and the monitoring studies. The high abundance of *A. gossypii* reported in this study is in agreement with the work reported by Rongai *et al.* (1998) and Nderitu (1983).

However, during the long rains season, the population of *M. euphorbiae* increased at the Tigoni site to more than that of *M. persicae* as the season progressed and even surpassed *A. gossypii*. This can be compared with the field survey results where the same species *M. euphorbiae* populations increased from 3rd position at the Tigoni site to 2nd position at the Njabini area, which is at a higher altitude than Tigoni area. *M. euphorbiae* increased in proportion to be the most encountered species at the Molo area, which is at the highest altitude of the 3 survey areas. These results suggest that this species *M. euphorbiae* increases in population

proportion than the other species at low temperatures. Nderitu and Mueke (1986) had also found that at the middle of the long rains season, potato cultivars were heavily infested by *M. euphorbiae* populations. The order of abundance of the species is also significant to seed and ware potato production in the country. *M. persicae* and *A. gossypii* have been reported as the main vectors of virus diseases in potatoes (Pushkarnath, 1976; Khurana, 2000). The presence of these 2 species as the most abundant here suggests that potato production in the country is threatened due to transmission of virus diseases by these aphids. Proper control measures by the farmers are therefore necessary for these aphids. *M. persicae* has been reported as the most widely distributed potato aphid and the most important vector of potato viruses (CIP, 1996). However, in this study, *A.gossypii* was the most abundant and widely distributed followed by *M. persicae* in the warmer lower Tigoni area, while *M.euphorbiae* was the 2nd most abundant in the upper colder areas like Njabini. This result, plus the finding that the lower areas (Tigoni) had more aphids than the upper AEZs in Njabini and Molo shows that seed potato production should be encouraged more at the higher altitude AEZs to reduce the risk of infestation by aphids and infection by Virus diseases. Previous studies have reported that high altitude affects the activity of aphids due to limited flight (Bertschinger, 1992). Radcliffe (1982) also observed that low temperature (below 17.7 °C) reduces flight of alate aphids.

The aphid populations at the on-station experiments were significantly much lower in plots where aphid control chemicals were used than in those where no control measures were applied. These results on aphids agree with those of the other two studies (Field survey and the on-farm monitoring) where it was also found that aphid populations were low in farms where aphid control measures were applied. Insecticide use in the control of aphids is an indirect means of control of potato viruses for example PLVR and PVY (Woodford and Gordon, 1990).

As for the virus incidence, plots where certified seed was used had virus incidence that was significantly lower than those where uncertified seed was used. The viruses encountered were the same in order of occurrence as for the other two areas of study (Field survey and on-

farm monitoring) with PVS as the most encountered virus followed by PLRV, PVY and PVX. This finding again differs with earlier reports that PLRV, PVY and PVX are the widely distributed viruses. PVX was even once considered as a "healthy Potato virus" due to its wide distribution but little effect in reducing potato yields (Salazar, 1996). However, the finding in this study has shown that PVS is the most widely distributed virus though its effect on yields has been reported to be mild. This finding was in agreement with similar findings at the National potato research centre, Tigoni where PVS was found to be positive in more samples than the other three viruses, PLRV, PVY and PVX (Personal Communication, 2002).

There was more yield loss in the plots where uncertified seed was used compared to where certified seed was used. This implies that farmers need knowledge on the importance of use of certified seed and proper aphids and virus diseases management control measures if the production of ware and seed Potato is to be sustained in Kenya. The need to disseminate information on certified seeds for wider adoption has also been asserted by Walingo *et al.*, 2002.

6.2 CONCLUSIONS AND RECOMMENDATIONS

The results of these studies show that the yield of potatoes is significantly reduced by infections of virus diseases. Since these virus diseases are spread by the aphid vectors, it is very important that the aphid populations are controlled so as to reduce the spread of the virus diseases in potatoes. It is also evident that even with control of the aphid populations, the virus diseases were still prevalent if virus infected (uncertified) seed were used by farmers. It is therefore very important that, apart from controlling the aphid populations, farmers should be encouraged to use certified seed in order to reduce virus spread through seed. It was also clear that most farmers prefer using their own seed either because they cannot afford the cost of the certified seed or the seed is virtually unavailable to most farms. This is a constraint that farmers have had for some time. It would therefore be recommended that proper training be done in farm based seed potato production areas. This should be to teach and demonstrate to the farmers on how to identify the virus disease symptoms, how the viruses reduce yields of their potatoes and how they can select relatively clean seed after planting certified seed so that they can plant this seed for a few seasons before they can go back to replenish the seed with certified seed. This would reduce the cost of buying seed and also reduce yield loss due to viruses, as farmers will plant relatively clean seeds even when selected from their own farm. Farmers should also be encouraged to control the aphid populations so as to reduce virus spread from the few potato plants that could be infected and which the farmer fails to notice the symptoms. If this is accomplished, it is hoped that ware potato yields in the country would be maintained at reasonably high production levels.

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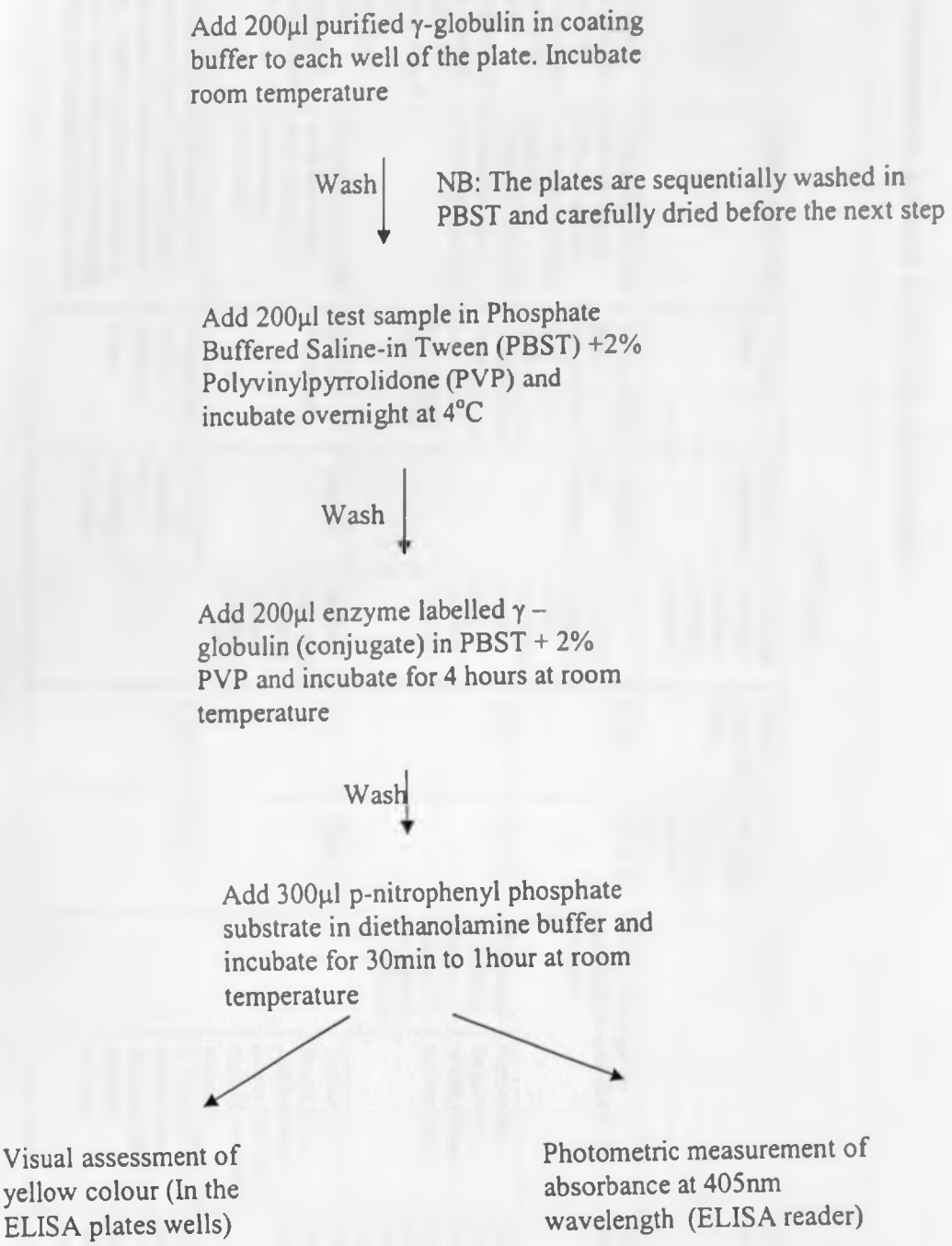
APPENDICES

Appendix 1: Agro-ecological zones coverage of the 3 survey areas-Tigoni, Njabini and Molo.

Area-District	AEZ	Description	Rainy Season	Potato Potential
Molo - Nakuru	UH_1	Upper highland -zone1. Sheep-dairy zone. Here mainly forest reserve. Very long cropping season dividable in two variable cropping seasons.	1st rains - start normally March, 2nd rains start normally end of June	Potatoes give good yield potential (60-80% of optimum) in both 1st and 2nd rains. If planted end of August onward, yield expectation is only fair.
	UH_2	Upper highland -zone2. Wheat-pyrethrum zone with very long cropping season dividable in two variable cropping seasons.	1st rains start normally end of March. 2nd rains - start normally beginning of July - 685mm (May-Sept) surpassed in 6 out of 10 years (**NB** - Start and end of rainy season in the whole district is not very distinct especially 2nd rains; In some places, there is even a third peak. So planting times are variable)	Potatoes give good yield potential in the 1st rains (March-July) and fair yield potential in the 2nd rains (Aug-Nov) 50-60%).
Njabini - Nyandarua	UH_1	Upper highland -zone1. Sheep and dairy zone with permanent cropping possibilities dividable in a long to very long cropping season followed by a medium one.	1st rains-start normally mid March 790-940mm. 2nd rains start normally mid Oct.- 420mm surpassed in 6 out of 10 years.	Potato gives good yield potential (60-80% optimum) in both 1st and 2nd rains
	UH_2	Upper highland -zone2. Pyrethrum-wheat zone with very long cropping season and intermediate rains dividable in two variable cropping seasons.	1st rains- start normally end of March-480mm (March-July). 2nd rains start indistinctly around Aug.- 565mm. (June-Dec) is surpassed in 6 out of 10 years.	Late maturing potatoes give a good yield potential in the 1st rains and all potatoes give a fair yield potential in the 2nd rains.
Tigoni - Kiambu	LH_1	Lower highland -zone1. Tea-dairy zone with permanent cropping possibilities dividable in long to very long cropping seasons, followed by a medium one.	1st rains - start normally mid March -740mm. 2nd rains- start normally mid October - 550mm surpassed in 6 out of 10 years.	Potatoes give good yield potential in the 2nd rains (Sept-Jan.)
	UM_1	- Upper midland -zone1. Coffee-tea zone with a fully long rain cropping season, intermediate rains and medium one.	1st rains - mid March 2nd rains - Mid Oct.	Marginal potato production
	UM_2	Upper midland -zone2. Main coffee zone	1st rains - mid March 2nd rains - mid Oct.	Marginal potato production
	UM_3	Upper midland -zone3. Marginal coffee zone	1st rains - mid to end of March 2nd rains - mid Oct.	Marginal potato production

Appendix 2: Standard procedure for carrying out microtitre plate Double Antibody Sandwich Enzyme Linked Immunosorbent Assay (DAS-ELISA) technique for potato virus detection



Appendix 3: Identification features of different aphid species

SPECIES	APTERAE									ALATE	
	Lateral abdominal tubercles / Spiracles	Antennal tubercles	Colour in Life	Shape of siphunculi	Secondary rhinaria on third antennal segment	Number of caudal hairs	*Process terminalis* base VI antennal segment ratio	Siphunculi		Dorsal abdominal pigmentation	Secondary rhinaria
Macrosiphum euphorbiae	Lateral abdominal tubercles absent from segments 1 and 7. Spiracles of abdominal segments 1 and 2 placed close together, their pigmented areas almost touching.	Antennal tubercles well developed with their inner margins diverging distally	Green with a paler longitudinal mid-dorsal band	Cylindrical or Tapering.	1 to 7 placed in a group on the basal third of the third antennal segment	8-12	About 5	Band of hexagonal reticulation over distal one seventh.		Absent, Completely green dorsally	Confined to the third antennal segment.
Aulacorthum solani		Antennal tubercles well developed, inner sides parallel	Green with a darker green area at the base of each siphunculus.			6-8	About 4	Siphunculi without distal band of hexagonal reticulation	Siphunculi longer than width of head across eyes.	Abdominal segments with entire or broken black transverse bars which may more or less fuse to form a broken black patch.	
Myzus persicae		Antennal tubercles well developed, their inner sides converging anteriorly	Green to olive-green	Clavate	Absent from third antennal segment of apterae	5-7	About 3		Siphunculi longer than width of head across eyes and than III antennal segment.	Abdomen always bearing a dorsal black patch.	Secondary rhinaria confined to the third antennal segment
Aphis gossypii	Lateral abdominal tubercles on segments 1 and 7 well developed. Spiracles of abdominal segments 1 and 2 widely separated, placed on either side of the lateral abdominal tubercle. Antennal tubercles absent.		Green, olive, yellow, orange or black.	Antennal tubercles little developed or absent		5-10	$2^1/_3$-3		Antennal hairs shorter than diameter of III antennal segment.	Abdominal segments with more or less developed black transverse bars, never forming a black patch.	Secondary rhinaria either on III only or on III and IV antennal segments.

Appendix 4: QUESTIONNAIRE (for field survey)

Name of the farmer_____ Male/Female_____
Province_____District_____Division_____
Location _____ Village _____ Plot No_____
Total Size of the farm _____ (ha), AE Z_____ Enterprises on the farm _____
1 _____ 2 _____ 3 _____ 4 _____ 5 _____
Area under Potatoes; (1) Ware_____(ha), (2) Seed_____ (ha)
Varieties grown as seed potato1 _____ 2_____ 3 _____
Varieties grown as ware potato 1 _____ 2_____ 3 _____
Varieties Preferred 1_____ 2 _____ and Reason _____
Source of Seed _____ Cost per kg_____
Method of Cultivation (agronomic practices); - Fertilizers, chemicals, seeds

_____
Major diseases on Potato; - 1 _____ 2 _____3 _____
Major pests on potato; - 1 _____ 2 _____3 _____
Knowledge of virus diseases by the farmer (their symptoms and impact on potatoes)

At what stage of crop growth does the farmer notice the disease _____
Yield per season (kg /ha) _____
Cultural practices; - (i) Number of weedings _____ (ii) Crop rotation practices _____
(iii) Planting time _____(iv) Intercropping (If yes, -with which crops)
1. _____ 2_____3. _____
Crop Protection management practices_____
If sprayed, chemicals used: For what diseases: Number of sprayings
1. _____ ,_____, _____
2. _____, _____, _____
Estimated crop loss due to virus diseases (per variety)
1, _____2_____3_____4_____(%)
Disease incidence (calculated from every variety)
1, _____2_____3_____4_____(%)
Samples of virus diseased and aphid infested leaves to be put in paper bags, labelled and taken to the laboratory for virus identification and aphid counts and identification respectively.
Where is the crop marketed? _____ Price per kg _____
Constraints in crop production _____
Uses of the crop _____
Do you use certified seed or use your own seed. _____
Farm Resources _____
Socio-economic characteristics; -
Age of the farmer _____ Experience in farming_____(years)
Who is the decision-maker on the farm? _____
Adoption of crop protection practices _____
Source of information on crop protection practices. _____
Do you store potatoes after harvest _____ If yes, for how long _____