INCIDENCE OF POTATO (*Solanum tuberosum L.)* VIRUSES AND EFFECT OF MAIZE BORDER CROP PLACEMENT ON APHIDS AND VIRUS DISEASES

BY

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DECLARATION

This is my original work and has not been presented for a degree in any other university

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DEDICATION

To the all powerful God

For his unconditional love

To my husband Edward Kinyungu and

Children Mercy Njeri, Grace Wanjiku and James Mungai

For their prayers, endurance and emotional support during the training period

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
M	Meter
C.V	Coefficient of Variation
MOA	Ministry of Agriculture
CIP	International Potato Center
PLRV	Potato leaf roll virus
PVA	Potato virus A
PVM	Potato virus M
PVS	Potato virus S
PVY	Potato virus Y
PVX	Potato virus X
Ha	Hectare
KARI	Kenya Agricultural Research Institute
Kg	Kilogramme
Gm	Gramme
LSD	Least Significant Difference
ELISA	Double Antibody Sandwich Enzyme-Linked Immunosorbent Assay
NPRC	National Potato Reasearch Station
DAO	District Agricultural Officer

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

ABSTRACT

A survey was carried out using structured questionnaire in six districts and twelve markets to establish seed potato production practices and incidence of potato viruses in farmers' produced seeds. Samples of potato tubers were also collected for serological analysis of viruses using Double Antibody Sandwich Enzyme-Linked Immunosorbent Assay method. A field experiment was also conducted at National Potato Research Centre, Tigoni over two seasons to determine the effect of maize border crop placement on aphids and aphid-transmitted viruses in Irish potatoes. The maize border was placed at 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 metres. Data collected from the field experiment was on population of aphids, virus disease incidences, virus titre, plant height and tuber yield. Data obtained was analyzed using Statistical Package for Social Science and GenSat software.

The survey revealed that all the farmers interviewed had used their own seed potato and only 1.6% of the farmers sourced seed from research stations. Tigoni was the most preferred variety by most farmers (25.8%), while Nyayo was the most preferred variety by the traders. Farmers considered high yields in the choice of a new variety and chemical control was the most preferred method for the control of pests and diseases. Fifty percent and 49.2% of the farmers had seen virus disease symptoms and aphids in potatoes respectively. Majority of the farmers (46.7%) obtained less than 2 tons/acre. The incidence of virus and virus titres in tubers differed among districts and retail markets and the viruses detected were potato leaf roll virus, potato virus A, potato virus M, potato virus S, potato virus X and potato virus Y. Potato virus S was the most prevalent viruses in the farmers' produced seed potato. There were significant differences among the districts in the incidence of all the viruses, except potato virus A and potato virus S.

There were significant differences among the districts in the titre of all the viruses except Potato leaf roll virus and Potato virus Y.

From the field experiment the aphid species identified were, *Myzus persicae*, *Macrosiphum euphorbiae*, *Aphis gossypii*, *Aphis fabae* and *Rophalosiphum maidis.* The most abundant aphid species on the leaves during long rain season was *M. euphorbiae* while, *A. gossypii* was the most abundant in short rain season. *R. maidis* was the most abundant species in yellow waterpan traps during both seasons. Placement of maize border up to 1.5m and 1.0m had a significant reduction in virus disease incidences by upto 50% and 60% during short rain and long rain seasons respectively. Lowest virus titre was recorded in tubers from plots with maize border placed at 0.5 m and 1.0 m from potato while the lowest tuber yield was recorded in potato plots with maize border placed at 0.5 m.

Maize border crop can be used by farmers to reduce transmission of aphids and aphid-transmitted viruses in Irish potatoes. The effective distance for the placement of maize border is 1.0 m. However, there is need to carry out research to determine the number of seasons a farmer can plant seed potato harvested from plots with maize border crops before yields are reduced to uneconomical level.

CHAPTER 1: GENERAL INTRODUCTION

1.1 Background information

The potato has its origin in the Andrean Mountains and it expanded globally in the sixth century when the Spanish introduced it in Europe and latter spread to Asia in the seventeenth century (Hawkes, 1990; Staubli *et al.,* 2008). The potato cultivation in Africa was started in the nineteenth century (CIP, 2008). The crop is the most widely grown tuber crop in the world and it is ranked fourth as the most important food crop after maize, rice and wheat respectively (Gildemacher *et al.,* 2007). The United Nations officially declared the year 2008 as the International Year of the Potato in recognition of the vital role the crop plays in the peoples' livelihood in developing nations (MOA, 2008_a).

Under unfavorable weather conditions, potato yield more than wheat, maize and rice while providing more nutritious food from less land (CIP, 1984; Allemann *et al.,* 2004). Nutritively, the potato has more edible protein than other roots and tubers, and it is also rich in vitamin C, thiamin, niacin, vitamin B_6. phosphorus, iron, magnesium and potassium (Horton, 1987). The crop has a well-balanced protein to calories ratio and has low content of sodium making it useful in salt-free diets (CIP, 1984). The crop is second to sweet potatoes in production of energy per hectare, while it best suited for intercropping with other crops (Nganga, and Shideler, 1982). Potato production in the world has been increasing steadily and in 2007 the total production was 325.3 million tonnes, with the developed countries producing 159.89 million tonnes (FAOSTAT, 2007).

In Kenya the crop is rank second after maize and it plays a major role as a food security crop, reduction of hunger and as a source of income for farmers (Kabira *et al*., 2006; MOA, 2008_a). The potato in Kenya is grown mainly by small scale farmers, many of them women, although some larger-scale growers specialize in commercial production (Gildemacher *et al.*, 2007; CIP, 2008). The potato industry employs 2.5 million people, and 500,000 of them are farmers directly involved in its production (KARI, 2007; MOA, 2008_a). The main potato growing areas include Molo, Mau-Narok, Bomet, Nakuru, Koibatek, Kericho, Ol-Kalou and Kinangop, Nyandarua, Kiambu, Uasin Ngishu, Embu and Trans zoia (Crissman, 1989; KARI, 2007; MOA, 2008). There has been a steady growth in the area under potato from 2,400 hectare in 1939 to 5,100 hectare in 1970 with a production of 16000 and s40800 ton respectively (MOA, 2005). The average total annual production in the country is between 670,300 and 1,050,000 ton harvested from 90,000 to 10,000 hectares in two growing seasons (Kabira *et al.*, 2006_a). In 2007 the area under potato was 98,401 hectares with a total production of 1,968,020 tons (MOA, 2008). The average yield is below 10 tons/ha as compared to 40t/ha achievable under research condition (Kabira *et al.*, 2006_a).

The research in the country started in 1967 when a potato development programme was established with the sole purpose of screening local varieties, find solution to farmers' problems and produce adequate high quality seed varieties (Waling *et al.*, 2002). To support the programme with research facilities, Potato Research Station at Tigoni and three sub-centres at Marimba (Meru), Marindas (Molo) and Njabini (South Kinagop) were established (Njoroge, 1982; MOA, 2005). Despite this intervention by the government, shortage of seed persisted due to inadequate seed produced which did not reach all the farmers (Kabira *et. al.*, 2006). Farmers who were purchasing seed from the programme did not multiply the seed further but sold the harvested crop as ware potato to other farmer (KARI, 2008). To solve this problem, the government established a commercial oriented seed potato production programme in 1997 under the Agricultural Development Corporation (ADC) (MOA, 2005). Seed potato originating from ADC was distributed and sold by Kenya Farmers Association (KFA) while the extension service of the Ministry of Agriculture was involved in promotion of the certified seeds (Njoroge, 1982; Crissman, 1989).

Seed used in the country originate either from the formal or informal production system (Crissman, 1989). The formal production system produces less than 1% of the seed requirement in the country with the gap met by farmers using their own retained seeds or purchase from informal sector (Kinyae *et al.*, 1994.*)*. The formal seed production system involve certification process that include registration, field inspection, lot inspection, sampling for pest control plots, labeling and sealing (Njoroge, 1982). The process of certification is undertaken by Kenya Plant Health Inspectorate Service (KEPHIS) (MOA, 2005). According to the Kenya gazette supplement no. 38 of 27th May, 2005, proportion of plants showing virus symptoms should not exceed 10%, 3% for bacterial wilt and 3% for nematodes (MOA, 2007). Some of the seeds produced by Kenya Agricultural Research Institute multiplied is further by community based organizations, individual farmers and other government runs institutions which go through the certification process (KARI, 2008).

The informal seed production system entails seed potato production without going through the certification process. Informal seed producers include non-registered growers and suppliers of seed mainly in their immediate localities. It also includes farmer to farmer distribution, and the sector supplies more than 99% of the 300,000 tonnes seed required annually (MOA, 2005). To address the quality of seeds originating from the informal system, research stations have been selling certified seeds to farmers which are later multiplied and sold to other farmers (KARI, 2008). Owing to the small sizes of land holdings, farmers have been bulking seed in groups which also has an advantage of attracting a non-government organization while at the same time they have a bargaining power over the selling price (Kidanemariam *et al*, 1999). In 2004 and 2005, International Potato Centre (CIP) in collaboration with KARI and Ministry of Agriculture introduced the concept of positive selection (Gildemacher *et al.*, 2007). Positive selection was introduced to small scale farmers' seed producers in Narok district on a pilot basis and it has since spread to other parts of the country

(KARI, 2007). The aim of the project was to reduce crop degeneration caused by seed-borne diseases (Kabira *et al.*, 2006). Positive selection involves selection of the healthy-looking mother plants showing good production characteristics, for seed collection (Kabira *et al.*, 2006_a). Potato yields realized from seed potato from positive selection programme doubles compared to seed potato from other informal sources due to reduction of diseases (Ayieko and Tschirley, 2006).

The country ranks high among potato consumers and producers in Africa (CIP, 2008). The production per capital of the potato crop in Kenya is 5 to 40 kilogrammes (Thelsen and Thiele, 2008). The potato tubers are utilized as boiled, baked, fried, roasted or in mashed form (Walingo *et al.*, 2004). French fries are the major form of value addition in the urban areas, while there are few food processing industries producing crisps (Kabira, 2000). The crop also has a great potential in industries as raw materials for starch, soap and animal feed production (MOA, 2008). There has been increasing consumer preference for potatoes in rural areas as a staple food and as French fries and potato crisps in urban areas (Walingo *et al.*, 2004). The crop also has a high potential in export markets of fresh and processed products from Irish potatoes, and currently negligible amount of ware potato is sold to Seychelles and as well as informal cross border trade with Tanzania (MOA, 2005). There is need to increase production of potatoes at the farmers' farms to meet the increasing demand in local and also exploit the potential market of potatoes (KARI, 2007).

1.2 Problem statement and justification

Constraints facing potato production in the country are poor marketing infrastructure, high cost of inputs, low produce prices, inadequate certified seeds, dependence on rain with very little irrigation facilities, pests and diseases. (KARI, 2007; MOA/PSDA, 2007). The most pressing challenge in potato production in Kenya is availability of clean seed potato (MOA, 2008_a). In Kenya, both formal and informal seed production has been utilized in the production of potato seeds (CIP, 2008; KARI, 2008). The formal seed production accounts for less than 1% of the total seed requirement and the balance comes from the informal sector (Kinyae *et al.*, 1994). Seed potato from the informal system comes from farmers' own seed potato, individual seed growers as well as group bulking seed including seed from positive selection programme (Gildemacher *et al.*, 2007; Crissman, 1989; MOA, 2005). The seed potatoes from informal sector are contaminated with diseases resulting in low productivity (Ayieko and Tirchley, 2006; Nyaga, 2008). Farmers recyle their own cycle from several harvests resulting in build up of pests and diseases in each consecutive year (Kabira, *et al.*, 2006). Among the diseases infecting tubers, viruses are the most important in terms of spread and huge losses in yield (Olubayo *et al.*, 2002, Were, 1996; CIP, 2008). Viruses have received very little attention although losses of up to 90% have been reported (Mih and Atiri, 2001). This coupled with low investment to enable accurate detection of virusesand limited knowledge on viruses has resulted to escalating problem of virus build up in the seed potato (Salazar, 1996).

In Kenya studies on viruses affecting Irish potatoes have been conducted in Timau, Kisii, Molo, Njabini and Limuru. The studies revealed that seed potato production practices by farmers' were poor and seed potato is highly infected with viruses (Were, 1996; Kibaru, 2003; Machangi, 2004; Nyaga, 2008). The seed potato tested for viruses were collected from the farmers' stores. Markets studies need to have been reported as one of the major source of seed potato used by farmers and therefore studies can be done to establish the presence of viruses in seed potato sold by retail traders.

The viruses reported infesting potato tubers have aphids as their vectors (Raman, 1985). The best approach to virus and aphid control involves combination of two or more control strategies involving cultural, chemical, physical, plant resistance, quarantine and certification (Difonzo *et al.*, 1996). Among the cultural control methods, border crops have proved to be effective in management of aphids and aphid transmitted viruses in a non-persistent manner (Kibaru, 2003; Muindi, 2008). The border crops have been effective in reducing the aphid population and virus load on the stylet of the aphid which can be transmitted to the potato crop (Fereres, 2000). Kibaru (2004) used maize, wheat, sorghum, common beans and garden peas as border crops and they were planted at 0.5 metres from the potato crop. Muindi (2008) evaluated the effect of maize, wheat and sorghum borders crops placed at 1.0 metres from the potato crop. The studies indicated that potato virus Y was lower in the potato crop with border crop than in the non-bordered crop. Higher aphid population was recorded in the non-bordered crop than in potato plots with border crops. However the effective distance of placement of border crop has not been determined for the management of aphids and aphid transmitted viruses in Irish potatoes. Further studies need to be done to determine the effect of border crop placement distances on aphids and aphid transmitted viruses. Therefore this study was conducted with the overall objective of establishing viruses affecting seed potato tubers produced small scale farmers in Kenya and to develop a management strategy of aphid and aphid-transmitted viruses using maize border crops.

The specific objectives were: -

i. To establish seed production practices and incidence of virus diseases in farmer produced seed potato

ii. To assess the effect of maize border crop placement on aphids and aphid-transmitted viruses in seed potato.

CHAPTER 2: LITERATURE REVIEW

2.1 Potato production in Kenya

Potato growing in Kenya was started in the nineteenth century when European settlers first introduced it in Kiambu, Muranga and Nyeri district. The purpose of introducing it was for domestic consumption and then later for export (MOA, 2005; KARI, 2006). Based on geographical and production practices, important potato growing regions can be divided into Mt. Kenya, Aberdare, Mau and Mt. Elgon regions (Kabira *et. al.*, 2006_a). The potato is mainly grown in high altitude areas that are 1500-3000 metres above sea level with average annual rainfall of more than 650 mm (MOA, 2008; CIP, 2008). It grows well in soils that are fertile, deep and well drained with a Ph range of 5.5-6.0 while a temperature range of 15-18^{0}C is best suited for potato growing (Kabira *et. al*, 2006_a; Gildemacher *et al.*, 2007). According to the Ministry of Agriculture the crop is grown in seven provinces in the country, with central province leading in area under the crop (MOA, 2008) (Table 2.1). In 2007 the area under potato was estimated at 98,401 ha with a total production of 1,968,020 tonnes which had the farm gate price of more than Kenya shillings 9.84 billion (MOA, 2008). This value increases to more than double at the consumer's prices (KARI, 2006; MOA, 2008_a).

A wide range of varieties are grown by farmers and different regions differ in preference on the varieties grown (Kabira *et al.,* 2006 $_a$). The two most commonly grown varieties in Kenya and are currently being promoted by National Research Potato Centre are Asante and Tigoni (Kibaru, 2003; Nyaga, 2008). These varieties have moderate tolerance to potato aphid population and also have low incidence of potato leaf roll disease (Munyua, 2006).

Table 2.1: Irish potato production 2006-2007 statistics in different provinces of Kenya

Province	Achieved hectares		Production in tones		Value in million Kenya shillings	
	2006	2007	2006	2007	2006	2007
Western	2,108	3,710	42,160	74,200	210.8	371,000, 000
Central	55,574	40,828	1,111,480	816,560	5,557,400	4,082,800, 000
Rift Valley	39,020	39,637	780,400	792,740	3,902,000	3,963,700, 000
Coast	10	10	200	200	1,000, 000	1,000,000
Eastern	21,451	12,933	429,020	258,660	2,145,100	1,293,300, 000
Nairobi	505	25	10,100	500	50,500	3,000, 000
Nyanza	2,086	1,258	41,720	25,160	208,600	125,800,000
Total	120,754	98,401	2,415,080	1,968,020	12,075,400	9,840,600,000

Source: Ministry of Agriculture 2008

Other varieties that the National Research Potato Centre, Seed unit is currently multiplying and selling to farmers are Dutch Robyjn, Desiree, Kenya Karibu and Kenya Sifa (KARI, 2007). Potato varieties being multiplied and grown by farmers include Kerr's pink, Nyayo, Roslin Tana, Arka Ngure, Changi, Mwezi moja, Annet, Kenya Baraka, Roslin Eburu(B53), Kenya Thamana, Kenya Chaguo, Kenya Mavuno, Kenya Faulu and Rosalin Bvumbe (Walingo *et al.*, 2004; Kabira *et al.*, 2006; Nyaga, 2008).

2.2 Constraints to potato production

There has been an increase in area under potatoes in the country over the years but yields per unit area have remained almost the same (MOA, 2005, KARI, 2007). Yields of potatoes has remained at below 10 tons/ha compared to 40 t/ha obtained under research conditions (Kabira *et al.*, 2006;

MOA, 2008_a). Growing of potatoes is hampered by high diseases and pest pressure (CIP, 1996; Caldiz, 2000; Olubayo *et al.,* 2004). Currently National Potato Research Centre and very few isolated groups are the only public institution producing certified seeds (MOA, 2005; Kabira, 2002).

There has been an acute shortage of certified seed potato to meet the demand in Kenya (MOA, 2008_a). The formal seed accounts for less than one percent of the total seed used in the country (Kinyae *et al.,* 1994; Ayieko and Tschirley, 2006; Gildemacher *et al.,* 2007). The seed produced through the formal sector is expensive and not accessible to the small-scale farmers. Certified seed is sold at Kenya shillings 38 per kilogram compared to Kenya shillings 13 per kilogram of local variety and seed from positive selection programmes. This has resulted in farmers using their own recycled seed potato, purchase from the market or from neighbours, which are mostly infected with disease (Kibaru, 2003; KARI, 2006; Gildemacher *et al*., 2007; MOA, 2008). High incidences of bacterial wilt and viral diseases have been reported to reduce yields by up to 90% at the farm level (Jayasinghe, 1988; KARI, 2006; MOA, 2008). Planting of uncertified seed potato results to low yields of 20-30 of one hundred and ten kg bags per acre compared to 40-60 of one hundred and ten kg bags per acre realized from certified and positive selection programme seed (Ayieko and Tschirley, 2006).

Late blight caused by *Phytopthora infestans* is the most important disease affecting potato worldwide (Hijmans *et al*., 2000). The disease attack leaves, stems and in advanced stage of infection may enter the tubers (Kabira *et al.* 2006). The disease also causes tuber blight reducing both the marketable and total yield of potatoes. An estimated annual loss of 31% in total yield and 23% loss in marketable yield have been documented due to the failure to used fungicides to control late blight (Dowley *et al*., 2008). Early blight caused by *Alternaria solani* has been found to be affecting mainly potatoes that are stressed or aged and it has little effect on yield as compared to late blight (CIP, 1996). The bacterial wilt caused by *Rastonia solanacearum)* ranks second worldwide, although it is the most important bacterial disease in the warm region of the world. The disease can kill the whole plant and the pathogen is mainly transmitted through infected tubers (CIP, 1996; Kinyua *et al.*, 2001).

Viruses are important diseases of viruses and their effect on Irish potatoes has been gaining importance (CIP, 2008). More than 35 different viruses are known to infect potatoes (Mih and Atiri, 2000). Potato leaf roll virus (PLRV), Potato virus Y (PVY), Potato virus S (PVS), Potato virus M (PVM), Potato virus A (PVA) and Potato virus X (PVX) are the most important viruses in potatoes in terms of their distribution and their effect on yield (Salazar, 1996; Corral, 2001). Potato leaf roll virus and strains of PVY are the most prevalent and harmful viruses worldwide (Difonzo *et al*, 1996; Serkaya and Serkaya, 2005). These viruses occur either singly or in their combination, and the combination of mild viruses (PVS and PVX) with other more severe viruses (PLRV and PVY) result in an increase in reduction on the potato crop yield (Machangi *et. al.*, 2004, Pourrahim and Farzadfar, 2007; Olubayo *et al.*, 2002). Visual detection of some viruses is difficult because they do not show any symptoms requiring chemical tests that are expensive for the resource poor farmers (Salazar, 1996). Limited knowledge on virus diseases and aphid vectors control by the farmers has contributed greatly to spread of viruses in the farms (Kibaru, 2003; Nyaga, 2008). Potato crop infected with viruses can have yield reduction of up to 90% (Salazar, 2006). In addition, the potato spindle tuber viroid (PSTDd) and a few phytoplasma organisms can affect the yield of the crop through production of small tuber whose numbers are reduced (CIP, 1996). The most important mode of transmission is mechanical and through infected tubers. Symptoms associated with PSTDd are misshapen, elongated tubers with pointed ends which reduce the quality of tubers (Mazhaeva *et al.*, 2006).

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The crop is a host of seventy species of insects, fifty two of which are pests and seventeen are predators of these pests (Nderitu, 1991). Potato tuber moth (*Phthorimaea opercillella)* Zell, and aphids are the two most important insect pests of potatoes. Other pests infesting potatoes are leaf miner *Liriomyza* spp, Blister beetle (Epicauta spp.), thrips (*Franklinella* spp., *Thrips* spp) and cut worms (*Agrotis* spp). Aphids are the most important pests of potatoes, which transmit viruses in the tubers (Boukhri-Bouhachem *et al.,* 2007; Townsend, 2007*).* The most important and widely distributed aphid species is *Myzus persicae* which persistently transmits potato leaf roll virus as well as other non-persistentlt tranmitted viruses (Raman, 1985).

The effect of aphid infestation on the potatoes can broadly be categorized into direct or indirect (Godfrey *et al*, 2000). The direct effect of aphid activity on the hosts include sucking of plant sap containing plants nutrients, injection of saliva and interference with the physiological systems of the plant (Minks and Harrewijin, 1989; Townsend, 2007). High population of aphids on a plant causes considerable injury through sucking of plants sap and the plant respond by having leaf roll, wilting, stunting of shoot growth as well as delay in production of flowers and fruits (Kabira *et al.*, 2006). Aphids cause indirect damage to their hosts through honey dew excretion and deposition and virus transmission (Bernhard and Dixon, 2005). Honey dew coated objects later on become covered by one or more black or brown fungi known as sooty molds which interfere with photosynthesis in leaves of the host (Townsend, 2007). Among the indirect damages, transmission of viruses by aphids is the most important (Mih and Atiri, 2000).

Potato is mainly marketed in the domestic market, which is liberalized with little government intervention (Walingo *et al.*, 2004; MOA/PSDA, 2007). The marketing system in Kenya is long and it is not well organized (Gildemacher *et al.,* 2007). It is estimated that over 80% of commercially marketed potatoes go through brokers who form cartels at both ends of the marketing channels

(KARI, 2007). The market information flow is controlled by brokers who form cartels in urban markets and producing areas thus manipulating prices to the disadvantage of the growers (MOA, 2005). Potato production in the country relies on rains and this coupled with high perishability and lack of adequate storage facilities influences the prices (CIP, 2008_a; MOA, 2005; Walingo *et al*., 2004). Other market related constraints in potato production are poor infrastructures, little value addition and excessive taxation at different levels within the marketing chain (MOA/PSDA, 2007). The standard weight of 110 kg bag of packaging of ware potato as specified in the Kenya Gazette Supplement No. 38 of 25th May, 2005 has not been complied with leading to low income from sale of potatoes (KARI, 2006; MOA/PSDA, 2007).

To address some of the marketing constraints facing potato sub-sector, an association was formed, Kenya National Potato Farmers' Association currently called KENAPOFA in 2004 (MOA/PSDA), 2007). The association was officially registered in March 2006 and it held its first grass-root election in October and November of the same year (KARI, 2007) The organization was mandated to recruit potatoes farmers and empower them through organizing training addressing crop husbandry and marketing issues (KARI, 2007). The association has been carrying out its activities in major potato growing areas although inadequate financing has slowed down their activities (KARI, 2008).

2.3 Aphid species infesting potatoes

Aphids are small-bodied bugs of the order; Hemiptera, Family; Aphididae that feeds on the sap in the plant phloem. There are more than 4,400 aphid species worldwide (Corral, 2001). Aphids are pests of great economic importance, and their importance is due to the fact that they are vectors of plant viruses which causes decline in quality and quantity of farm produce (Minks and Harrewijn, 1989). In potato production viruses can cause reduction in yield up to 90% in addition to loss of quality of tubers (Jayasinghe, 1988; Godfrey, 2000; Hanafi, 2000). There is great variation in the colour for many aphid species which can be associated with environmental factors, although they are notably weaker in species that live the whole year on one host (Zhou *et al.*, 1995; Harrington *et al.*, 2007).

Aphids occurs either as winged (alate) or wingless (apterae) morphs which differs in nymphal development period, reproductive period and length of life cycle (Braendle *et al.*, 2006). The winged morphs have a full set of wings that assist in the flight in addition to possessing sensory and reproductive features that is adapted to flight and reproduction in new areas. The wingless forms are responsible of high population increase due to their high reproductive capacity (Corral, 2001). The winged forms are usually triggered by environmental changes mainly photoperiod temperature, poor host nutrition and overcrowding (Karley, 2004; Muller, 2001; Simon *et al*, 2002). Presences of large number of predators also cause the aphids to release alarm pheromone which in turn triggers the aphids to give birth to winged morphs that leave the host plants (Kunert *et al., 2005*).

Myzus persicae (Sulzer) also known as the green peach aphid is the most widespread, polyphagous and efficient aphid vector species (Raman, 1984, Blackman and Eastop, 2000). This aphid has great variation in colour, life cycle, host relation as well as resisting insecticides (Braendle et al., 2006; Milosevic and Djalovi, 2007). The adults are 1.5 to 2.5 mm long and the winged forms are usually light green, deep pink to peach. The body is egg shaped with the posterior end being rounded; with an antenna that is almostly as long as the body (Martin, 1983; Raman, 1985).The winged adults have a black or dark brown head, thorax and a dark dorsal patch in the center of the abdomen. The cornicles are light coloured and slightly swollen towards the ends, while the cauda is light coloured and approximately half as long as the cornicles (Blackman and Eastop, 2007).

Green peach aphid feeds on hundreds of host plants in over fourty plant families. In temperate latitudes the primary or over-wintering hosts are trees of the genus *Prunus* spp, particularly peach and peach hybrids, but also apricot and plum (Raman, 1985, Capinera, 2005). During the summer months the aphids abandon their woody hosts for secondary or herbaceous hosts, including vegetable crops. It is capable of transmitting over 100 different plant viruses (Day, 1996). It is an important vector of potato virus Y and potato leaf roll virus which are of worldwide importance (Serkaya and Serkaya, 2005).

Macrosiphum euphorbiae is also known as the potato aphid. The aphid colonizes newer leaves and the growing tips of the plant (Berlandier, 1997; Raman, 1985). The body is pear-shaped with colour that range from solid pink, green and pink mottled or light green with a dark stripe. The wingless morph is 2.5 to 3.5 mm long and has a pair of long, slender conicles. On the head the tubercles are diverging and well developed, while the eyes are red.

Rhopalosiphum maidis is also called corn aphid. T.he adult aphid is a small to medium sized measuring 1.0-2.5 mm long with very short conicles. The aphid is pear shaped with short antennae and dark legs, siphunculi and cauda. The corn leaf aphids have colours varying from blue-green to grey. The aphid has a light green abdomen with a darker stripe in the middle. It is the most important aphid of the cereal in the tropics and warm temperate climates throughout the world (Blackman and Eastop, 2007).

Aulacorthum solani is also known as glasshouse aphid or foxglove aphid. The adult wingless morph is 1.5 - 3.0 mm long and has a pear-shaped body, with colours variation ranging from yellow, light green and green (Blackman and Eastop, 2000). The antennal tubercles are parallel while thorax and cauda are darker than the abdomen. On the dorsal part of the abdomen there are bright green or rusted green spots on the base of the each conicles. The conicles are long with black tips which are flared at the end.

Aphis gossypii is also called cotton or melon aphid has a wide host range infesting important crop and widely distributed in the tropics including many Pacific islands. The wingless aphids are 1- 2.2 mm in length. The body is quite variable in color ranging from light green, green, dark green, whitish, yellow, brown and red. It has short and black cornicles which are of the same length as the cauda. The cornicles are darker than the cauda. It has short hairs on legs and antennae, cauda is normally paler than the cornicles and they bear few hairs (Blackman and Eastop, 2007).

Aphis fabae, otherwise known as black bean aphid is a small rounded aphid measuring about 2.5 mm in length with a thorax that is darker than the abdomen. The body is black and it has short cornicles which are of the same length as cauda. The winged form has no abdominal marking or patch. It is polyphagous aphid infesting a wide range of crops in crop families (Blackman and Eastop, 2007).

2.4 Factors affecting aphid population

Aphid population fluctuates within season and over time giving rise to low and high peaks (Karley *et al*., 2004). There are various factors that contribute to this among them being aphid birth rate, host nutrition quality, extreme weather, emigration and migration of winged forms, and mortality as a result of increased natural enemies (Muller *et al*., 2001; Braendler *et al.*, 2006). The aphids have a very high reproductive rate and they reproduce both asexually as well as sexually (Burrows and Zitter, 2005). In the majority of aphids one sexual generation is followed by several asexual ones (Conrad, 2008).

Aphids display a high reproductive rate due to three peculiarities of their reproductive biology. First, during the spring and summer months, female aphids reproduce parthenogenetically, hence requiring no males (Braendle *et al.,* 2006). A wingless adult female aphid can produce 50 to 100 offsprings during their life with less than a dozen aphid colonizer producing hundreds to thousands of aphids on a plant in a few weeks (Townsend, 2007). Second, during these parthenogenetic generations, the embryos initiate development immediately after the budding of the oocyte from the germarium and young ones are born as fully developed first-instar nymphs (Day, 2005; Simon *et al.*, 2002). Finally the oldest embryos also contain embryos, so that adult parthenogenetic aphids carry not only their daughters but also some of their granddaughters within them (Braendle *et al.*, 2006; Stadler and Dixon, 2005). Generation after generation of wingless females survive on one another until hot weather comes or maybe the plant on which they are living dies and then suddenly some of the females grow wings and fly off (Conrad, 2008; Muller 2001). The clones resulting from asexual reproduction are not homogenous as a result of the progenies from asexual reproduction undergoing mutation (Loxdale, 2008).

With the return of autumn characterized by shorter days and cooler temperatures, a generation appears which includes both males and females and sexual reproduction occurs (Simon *et al.*, 2002). The male and female aphids mate resulting in production of yolk-rich eggs which are resistance to cold weather in winter and these eggs are glued to stems or any other part of the plant (Braendle *et al.*, 2006). The sexual phase can occur either on the same plant families as the asexual generation or on a different plant species in host-alternating aphids. When the weather become favourable, the nymphs which hatch from these eggs become wingless females known as stem mothers. There no males present during these times and parthenogenesis takes place (Muller *et al.*, 2001).

Environmental factors such as temperature, rainfall and wind effect aphid population, although temperature has been singled out as the most important factor that affects aphid behavior (Boukhris-Bouhachem *et al.*, 2007). Green peach aphid develops faster and has greater reproductive capacity under fluctuating temperature with the optimal temperature for its population growth being 26.7°C. Increasing temperature also accelerated aphid walking towards the host plants and also enhances migration (Narayandas and Alyokhin, 2006). Rainfall has been found out to delay migration, while severe rainstorms results in a drastic decline in aphid population (Cocu *et al.,* 2005; Karley, 2004). The alate aphids have been known to travel hundreds of Kilometres with the assistance of low-level jet winds despite their body looking plump and dumpy (Conrad,, 2008; Jayasinghe, 1998; Zhu *et al.*, 2006). The aphids undertake short as well as long distance flights. The long distance movement occurs from time to time, but short flights have a greater impact on population and their distribution (Loxdale *et al.* 2008). Host alternating aphids incur high death rates and these numbers lost are compensated by having high reproductive rates on primary host during spring (Dixon and Kundu, 1994).

Presence of other plant pathogens can also affect the number of aphids on a plant. *Aphis gossypii* has been reported to produce many more winged morphs on plants with the latest infection with virus than they do on either healthy plants or plants that have been infected sometime previously (McDonald *et al.,* 2003). Winged *Myzus persicae* are more likely to be found on virus-infected sugar beet leaves than on healthy leaves because the nutritional quality of such infected plants appears to be increased (Muller *et al.*, 2001). *Myzus persicae* and *Macrosiphum euphorbiae* have been reported to have a higher reproductive rate on mixed-infected plants than on singly-infected plants or non infected plants (Alvarez and Srinivasan, 2007).

A large number of biological agents, such as parasitoids, predators and pathogens, play an important role in the natural control of aphids. Natural enemies have the potential to suppress aphid population (Tanaka, 1995). Most species of aphids are attacked by hymenopteran parasitoids such as *Aphididius platensis*. They attach on the nymps, develop within it and it ends up killing it before pupation (Muller *et al.*, 2001). Some of the common predators which attack aphids include several species of lady beetles, lacewing larvae and syrphid fly larvae (Difonzo *et al.*, 1996). Fungal pathogen such as *Erynisa neoaphidis* has been responsible of reducing the aphid numbers over time (Nelson and Rosenheim, 2006). Some of the pathogens are disseminated across vegetation and geographic area by aphids on flights. Most of the fungal species carried by the alates are in ten species of obligate or non-obligate aphid pathogens with *Pandora neoaphidis* being the predominate one (Feng *et al.*, 2007).

2.5 Virus diseases of potato

Aphid-transmitted viruses account for approximately 50% of the 600 known viruses which have an invertebrate vectors (Hooks and Fereres, 2006). Throughout the world virus diseases constitute an important constraint to Irish potato production which is responsible of, reducing yield and quality of tubers (Biniam and Tadesse; 2007; Raman, 1985). The potato is infected by more than 39 viral diseases, and about half of these viruses are dependent on potato for their survival and spread (Mih and Atiri, 2000; Weingartner and Hooker, 2001).

The primary infection of the potato crop occurs when a healthy plant is infected by an aphid carrying the virus within the season, while secondary infection occurs when an infected tuber is planted, giving rise to an infected plant (Zitter and Gallenberg, 1984). Aphid transmitted viruses can be transmitted in a persistent and non-persistent manner (Raman, 1985). In the persistently transmitted viruses, virus has to be ingested by the aphid and it undergoes some changes before it is transmitted to another host (Gray and Gilda, 2003). The aphid transmits or acquires the virus when feeding on the phloem contents in the host cell. During feeding the aphid excrete salivary secretions through the stylets, and virus suspended in salivary secretions is thereby delivered to the host cell for infection (Alvarez *et al.,* 2007). Once the aphid is infected it remains infective for life. Among the potato aphids it is only potato leaf roll virus that is transmitted in a persistent manner (Raman 1985; Jayasinghe, 1988; Suranyi, 1999).

In a non-persistently virus transmission the virus particles adhere to the stylet of the aphid during the probing and feeding process of the host and non-host plants (Burrows and Zitter, 2005). The aphid can thus acquire or transmit such viruses within a very brief period thus the aphid loss ability to transmit after a very short period (Gray and Gilda, 2003; Jones 2003). The main factors influencing spread of the virus will depend on the initial virus inocula in seed crops, host plants, the status of aphids as colonizing or transient vectors in the crop (Robert *et al*., 2000). The factors that affect the symptoms expression and development in the potato plant that is infected by the virus are the potato cultivar, time of infection, type of virus or virus strains, mixed infection and the environment (Baldauf *et al*., 2006; Robert *et al*., 2000

Important viruses infecting potato belong to Luteovirus, Potyvirus, Potexvirus and Carlavirus groups and they are found wherever potatoes are grown (Burhan, 2007; Fletcher *et al*., 1996; Khartri and Shrestha, 2004). The viruses are transmitted through infected tubers and also by aphids making it important methods of transmitting the viruses from one season to another and also within seasons (Mih and Atiri, 2000; Raman, 1985). These viruses are either found singly or in multiple infections (Biniam and Tadesse, 2008; Saldan *et al*., 2002). The most important viruses in potatoes in terms of their distribution and their effect on yield are potato leaf roll virus (PLRV), potato virus Y (PVY), potato virus S (PVS), potato virus M (PVM), potato virus A (PVA) and potato virus X

(PVX) (Kang *et al*., 2007; Salazar, 2006). Some strains of mosaic viruses (PVS, PVX, PVY) produce no visible symptom of latent mosaic, but there is reduction of yield compared to non-infected plants (Godfrey *et al*., 2000).

Potato leaf roll virus (PLRV) belongs to the genus Polerovirus and it is associated with leaf roll symptoms (Kang *et al*., 2007). Potato leaf roll virus infects about 20 plant species in five plant families including potatoes and tomatoes (Difonzo *et al*, 1996). In the field PLRV is transmitted by several aphid species although Myzus *persicae* is the most efficient vector which transmits the virus in a persistent manner (Jayashinghe, 1988). The virus is also transmitted through infected seeds. Potato leaf roll virus can also be transmitted through by side cleft grafting of infected potato to *Datura stramonium* and *Physalis joridana* which is an important hosts for the maintenance and propagation of the virus (Arif *et al*., 1995). Potato leaf roll virus in combination with Potato spindle viroid results in huge reduction of on the potato yield as well as serious disturbances in sprout emergence of seed potato (Syller and Marczewski, 2001). Infected plants with PLRV produces fewer tubers and reduction of marketable tubers harvested from potatoes, with some varieties having necrosis symptoms in the tubers (Were, 1996; Jayasinghe, 1998; Hamm and Hane, 1999).

Potato virus Y (PVY) belongs to the genus Potyvirus and it is second most important virus after PLRV infecting potatoes worldwide(Suranyi, 1999). The natural hosts of the virus are affects solanaceous crops and weeds (Zitter and Gallenberg, 1984). The virus is transmitted in a non persistent manner by at least 50 different aphid species although *Myzus persicae* is the most important vector of this virus (Difonzo *et al*, 1996; Macdonald *et al*., 2003; Jones *et al*, 2003). The virus is also transmitted through the seed tubers (Crosslin *et al*., 2006; Burhan *et al*., 2007). The symptoms caused by the potato Y virus depend on the virus strain, potato cultivar, the time of inoculation (primary and secondary infection) as well as on the environmental conditions (Milosevic and Djalovic, 2002).

Potato virus Y is extremely variable in nature and several strains of PVY have been identified that differ by the symptoms they cause in potatoes (Baldauf *et al.,* 2006; Lorenzen *et al.*, 2006). Potato virus Y^O (PVY^O) is the ordinary strain, and it causes mosaic symptoms in the potato plant (Croslin *et al.*, 2006). Potato virus Y^C (PVY^C) is the stipple strain causing stipple streak while PVY^N, the necrotic strain, generally causes mild foliage symptoms, and also necrosis in the leaves of susceptible potato varieties (Baldauf *et al.*, 2006). Potato virus Y^{NTN} (PVY^{NTN}) induces necrosis in potato tubers which may be found at the stem end of the tuber or as raised necrotic rings around the tuber eyes (Baldauf *et al.*, 2006; Draper *et al.*, 2002; Milosevic and Djalovic, 2002). It is readily spread by aphids in a non-persistent manner as well as mechanically by human activity and may result in severely depressed yields (Noltle *et al.,* 2004).

Potato virus A (PVA) belongs to the genus a Potyirus (Radcliffe and Ragsdale, 2002). The virus has a wide host range and naturally *Solanum tuberosum L.* and S. betaceae have been found to be the natural hosts. Black and hairy nightshade weeds have been found to be infected with PVA making them important reservoir for the virus (Thomas, 2004).The virus is transmitted by aphids in a non persistent manner and from one season to the next through infected tubers (Mih and Atiri, 2000). The affected plant shows a mild mosaic, the margins of the affected leaves may be wavy, and at the veins they may be sunken while the interveinal areas are raised (Thomas, 2004; Zitter and Gallenberg, 1984). The plant tends to open up because the stems bend outward and the severity of symptoms expression depends on weather condition, the potato cultivar and the strain of potato virus (Godfrey *et al., 2000*). Potato virus A occurs where potatoes are grown and may result in reduction of potato yield of up to 40% (Zitter and Gallenberg, 1984).

Potato virus X belongs to the genus Potexvirus and it is one of the most widely distributed viruses of potatoes because no symptoms develop in some varieties (latent mosaic), the full extent of damage with PVX is not recognized (Zitter and Gallenberg, 1998). The virus is transmitted through the seed tubers and it has no known vector (Burhan *et al*., 2007). The virus can also be transmitted mechanically by machinery, spray equipment, plant parts contact and also seed cutting equipments (Godfrey *et al.,* 2000). The virus causes mosaic which is mild in some cultivars and sometimes latent (CIP, 1996). Virulent strains can cause slight leaf crinkling under period of low light intensity and low temperate of between 60°F to 68 °F (Qamar and Khan, 2003). Mixed infections of PVX with other viruses like PVY and PVA cause more damage than PVX alone The additional presence of PVA or PVY may cause crinkling, rugose mosaic or browning of leaf tissue. Infected potatoes may have a yield reduction of 15% or more compared to virus-free plants (Godfrey *et al.,* 2000).

Potato virus S (PVS) belong to the genus Carlavirus and it has a worldwide distribution. It is transmitted by aphids in a non-persistent manner as well as through tubers (Kang *et al.,* 2007); Mih and Atiri, 2000; Salazar, 2006). Most potato cultivars are symptom less although plants infected early shows a slight deepening of vein, rough leaves, a more open growth, mild mottling, bronzing and sometimes tiny neucrosis spots on the leaves (Burrows and Zitter, 2003). PVS can cause yield decline by up to 20% (Goffinet, 1982).

Potato virus M (PVM) belongs to the genus Carlavirus. PVM has only been detected in potatoes and the incidence of this virus is low compared to other viruses. The virus is transmitted by aphids in a non-persistent manner and is also tuber borne (Bock, 1982). Some cultivars of potato infected with

PVM may have yield reduction of 11-19.5% although its importance is when found in mixed infection with other viruses, 1984) (Mosahebi *et al., 2005*; Zitter and Gallenberg, 1984).

2.6 Management of potato aphids and viruses

The control measures that can be adopted in potatoes will depend on the intended use of the final product either for consumption or seed (Minks and Harrewjin, 1989). Potatoes are propagated primarily through the tubers making them important mode of transmission of viruses associated with them (Kang *et al*, 2007). Strict control measures are required for management of aphids and viruses in seed than ware potato since the potato industry is based on availability of quality disease free tubers (Raman, 1985; Difonzo *et al.,* 1996; Suranyi, 1999). In the management of aphids and viruses multiple tactics is the best and most sustainable solution, these multiple tactics involves cultural, chemical, physical, and biological (Difonzo, 1996; Jayasinghe, 1988; Townsend, 2007; Takada, 1995).

2.6.1 Cultural control

Cultural practices involve modification of pest's environment or habitat when measures such as field sanitation, crop rotation and intercropping are carried out (Takada, 1995). Cultural practices in the field are easy to implement and the cost involved is low. Planting of clean seed and elimination or exclusion of the vectors is the ultimate goal in plant in the field growing and seed in storage (Kibaru, 2003; Were *et. al*., 2003; Kabira, 2006). Aphids and aphid transmitted viruses can be reduced through elimination of volunteer potato crops and weeds that are likely to act as reservoir for them (Garriet and Guy, 1981). Hairy nightshade weeds are good reservoirs of PLRV and green peach aphid becomes viruliferous after feeding on them (Alvarez and Srinivasa, 2005). Control of these weeds is vital in production of the potatoes (Godfrey *et al*., 2000). Rouging of infected potato reduces the source of virus inoculum which can be transmitted to healthy plants (Jayasinghe, 1988).

When roguing virus infected plants after aphid colonization, plants surrounding the symptomatic plant should be removed because these neighboring plants may be infected, but not yet symptomatic (Mowry, 1994). This procedure is most practical when the incidence of virus infection is low and the field is small enough that every plant can be inspected several times during the growing season. This practice is important in seed production (Woodford and Gordon 1990; Godfrey *et al.*, 2000).

Early destruction of the haulms is important in reducing the infection of potatod tubers that are harvested and especially before the aphid threshold is reached (Suranyi, 1999; Jones, 2003; Sigvald, 2004). Environmental variables and aphid population in areas where seed production is being undertaken provides a guideline on the date to carry out dehaulming (Difonzo *et al.,* 1996*)*. Low-level jet duration also referred to as air current can provide a projection of current season *Myzus persicae* abundance approximately one month in advance of the usual onset of peak aphid flight activity. Advance prediction of aphid pressure or risk of virus spread would permit the grower for instance in a year of low risk not to choose to vine kill to increase tuber yield (Zhu *et al.*, 2006. Aphid population monitoring methods such as yellow water pan trap and suction traps has been used to provide data of some aphid to determine the time of haulm destruction. When the cumulative value reaches a certain threshold a date for haulm destruction is set to prevent virus infection of the tubers (Verbeer *et al.*, 2007). If the grower predicts that there is great risk of infection of the tuber destruction of the haulm can be delayed as the crop marketed for consumption or for industrial use (Sigvald, 2004).

In situation where the growers use seed from previous crop, healthy plants can be selected to be used as seed (Kabira *et al.*, 2006). These healthy plants have thick stems, dark green leaves and showing no disease symptoms, Pegging is done just before flowering and then check again for healthy and vigor two weeks later (Gildemacher *et al.*, 2007). Use of border plants crops has been used in control of non-persistently transmitted viruses (Fereres, 2000; Kibaru, 2004). The aphid lose the virus through the process of probing while it is searching for a suitable host (Hooks and Fereres, 2006; Olson, 2006).

2.6.2 Physical control

When virus infected plants are subjected to a higher temperature than normal the result virus is partially or completely inactivated without killing the plant (Chandniwala, 1999). Heat treatment of tubers at 37^0 C for one to two weeks can eliminate PLRV while a combination of thermotherapy for one week combined with meristem culture can eliminate PLRV, PVS and PVX (Biniam and Tadesse, 2008). Heat treatment at 35/30°C for one hour alternate has found to be highly efficient for the elimination of all PVY. In double infection of PLRV and PVY an additional of 20 mgL^{-1} mgL^{-1} ribavirin and 10^{-5} m acetylsalicylic acid and heat treatment at 35/30 for 8 hours alternate has been found to be the most effective (Fang *et al.*, 2005).

Straw mulch has been found to reduce aphid catches compared to the uncovered ground (Takada, 1995). Doring (2004) found higher number of alate trapped in yellow water traps that were placed in uncovered ground compared to white or silver background. Straw mulch is effective in reducing the aphid vector numbers in the seed potato crop and its effectiveness can be enhanced by pre-sprouting the seed that leads to early emergence and growth (Saucke and Doring, 2004). Fleece and netting can also be used to protect the potato crop from being infested by aphid resulting in reduction in virus transmission (Takada, 1995).

2.6.3 Chemical control

Chemicals used in the management of aphids are alarm pheromone, insecticides, mineral oils and repellants although the mineral oils and insecticides are the mostly used chemicals (Takada, 1995; Conclaves and Bleacher, 2006; Le-Fever *et al.*, 2007). Chemicals have been more effective in controlling *Myzus persicae* that transmit potato leaf roll in a persistent manner (Suranyi, 1996). Proper monitoring of the pest should be carried out and application to be done once the recommended threshold for the particular pest is arrived at in an attempt to use the chemical when it is necessary (Santanu and Kunar, 2005; Robert, 1995; Jones, 2003). Mineral oil has been found to reduce both persistently and non-persistently transmitted viruses in potatoes (Suranyi, 1996). The acquisition and inoculation of a virus by the aphid is reduced by the presence of oil on the potato plant surface (Powel, 1991). Continuous use of insecticides has resulted to sexually produced morps of *Myzus persicae* (green peach) that develops resistance making it difficulty to eradicate the vector (Guillemaud *et al.*, 2003; Corral, 2004; Castle and Tascano, 2007).

2.6.4 Certification and quarantine

Quarantine regulation in seed production include all forms of legislation and regulation that may prevent establishment or reduce spread of pest or disease while certification programmes entails elimination of virus in tubers (Minks and Harrewijin, 1989). Tubers from seed field that exceeds certain infection level of seed certification regulation are not used as seed but it is sold for consumption at a lower price (Jayasinghe, 1988). Under the European and Mediterranean Plant Protection Organization (EPPO) procedures testing are carried out as specified for seedling derived from true seeds, tissue culture, tubers and rooted cuttings which also include serological for certain viruses (EPPO, 1998). In the USA, soon after potato plantlets are initiated into tissue culture, serological test is carried out for PVA, PVY, PVX, PVM, PLRV, Potato moptop virus, Tobacco rattle virus, Alfalfa mosaic virus and Tomato spotted wilt virus (Difonzo *et al.*, 1996). Serological procedure combined with Reverse Transcription- Polymerase Chain Reaction (RT-PCR) can be employed especially in detection of viruses that occur in strains (Crosslin *et al.*, 2006).

2.7 Use of barrier crops in management of potato aphids and viruses

Barrier crop or border crops can be defined as trap crops that are taller than the main crop and are planted on border of the field as a means of controlling pests (Shelton and Badenes-Perez, 2006). Barrier plants are a management tool based on secondary plants used within or bordering a primary crop for the purpose of disease control (Fereres, 2000). Where trap crops where they have been successfully implemented, it has provided a sustainable and long- term management solution to control difficult pests (Suranyi, 1999). Border plants become effective with the increase in growth thus providing a suitable environment for increase in natural enemies through provision of hiding place and diversity providing food resources for the natural enemy (Ebwongu *et al.,* 2001). Aphids are attracted to green-dark interface on the field edges resulting to great number of the aphids on them in search of a suitable host (Doring *et al.*, 2004; Suranyi, 1996).

Border crops have been used in reducing the spread of non-persistent transmitted aphid-borne viruses by acting as a natural sink. This would reduce significantly the viruses spread and also result in an increase in yield (Kibaru, 2004; Yvon, 2000). Barrier plants should be a non-host for the virus and the vector, but appealing to aphid landing and attractive to their natural enemies and should allow sufficient residence time to allow aphid probing before taking-off occurs (Hooks and Fereres, 2006). A viruliferous winged aphid searching for a host plant will alight in the barrier crop, probes after which it losses its infectivity before entering the area of the susceptible primary crop (Difonzo *et al.*, 1996). Success of barrier plants depends on the height of the barrier crop at the time of maximum risk of the primary crop; virus spread pattern and competition of barrier crop and the protected crop (Corral, 2001).

In Kenya, border crops such as sorghum, millet, pigeonpeas, broad and maize have been used in management of aphid-transmitted potato virus diseases (Kibaru, 2004; Muindi, 2008). Border crops of pigeonpeas, used in okra were found to be effective method in management of aphids (Nderitu *et al.*, 2008). Effectiveness of border crops can be improved through use of other control measures such as use of insecticide. Incorporation of insecticides in the border crops has recorded further reduction of these aphids and the viruses they transmit (Suranyi, 1999 Muindi, 2008). Boiteau *et al.* (2008) found out that controlling aphid with oils reduced year to year variation and it was effective than crop border crop or oil sprays used separately. The mineral oil spray was applied on the border crop reducing the number of aphids that would transmit the virus to the main crop.

CHAPTER 3: SEED POTATO PRODUCTION PRACTICES AND INCIDENCE OF VIRUSES IN FARMER PRODUCED SEED POTATO

2.1 Abstract

A survey was carried out using structured questionnaire in six potato growing districts and twelve markets to establish seed potato production practices and determine incidence of viruses in farmers' produced seed potato. Samples of seed potato tubers were collected for serological analysis by Double Antibody Sandwich Enzyme-Linked Immunosorbent Assay. Information obtained included land sizes, area under potato, varieties of potato grown, source of seed potato, agronomic practices, pests and diseases management practices, storage practices yields. Data obtained was analyzed by Statistical Package for Social Science and GenSat computer soft ware package.

All the farmers interviewed were using their own seed tubers and 1.6% of the farmers had sourced seed potato from KARI, Tigoni research centre. Tigoni was the most preferred variety by the most farmers (25.8%), while Nyayo was the most preferred potato variety by the traders. Fifty five percent and 49.2 % of the farmers had seen virus disease symptoms and aphids respectively. Majority of the farmers (46.7%) were harvesting less than 2tons/ha of potatoes. The viruses detected in tubers were potato leaf roll virus, potato virus A, potato virus M, potato virus S, potato virus X and potato virus Y. The most prevalent virus was potato virus S and there were significant differences among the districts and markets in the incidence and virus titre of all the viruses. There were significant differences among the markets in virus incidence of all the potato viruses, except potato virus Y.

The result indicated that seed potato from the farmers is contaminated with viruses and therefore there is need to clean, multiply and distribute preferred varieties. Given, that farmers own small parcels of land, bulking by farmers' groups can be done for the supply of seed potato, and incorporate control methods to reduce re-infection with viruses .

3.2 Introduction

Irish potato is the second most important food crop after maize (MOA, 2008). The crop is mainly confined in the cooler highland areas and it requires rainfall of more than 650 mm of rainfall (Kabira *et al* 2006 $_a$). The main potato growing areas include Molo, Mau-Narok, Bomet, Nakuru, Koibatek, Kericho, Ol-Kalou and Kinangop, Nyandarua, Kiambu, Uasin Ngishu, Embu and Tranzoia (Crissman, 1989; KARI, 2007; MOA, 2008). The crop is grown for food security, income generation and creation of employment for people involved at different level of the value chain (Kabira *et al.*, 2006; MOA, 2005; MOA/PSDA, 2007). Seed potato from the formal system accounts for less than 1% of the total seed requirement in the country but it is expensive and out of reach for majority of small scale farmers (Kinyae *et a.l,* 1994; Ayieko and Tschirley, 2006). The basic seed potato produced by KARI Tigoni is mostly sold to farmers involved in ware potato production and majority of farmers who purchase the seed potato are from neighbouring districts (KARI, 2008).

As a result of seed potato shortage in the country, informal seed potato production has been started to fill the gap (Crissman, 1989; KARI, 2008). The informal seed producers include private growers, groups which may be supported by non-governmental organizations and individual farmers involved in positive seed selection (MOA, 2005). The seed produced from the informal system is planted for several years without replacement resulting in build up of pests and diseases (Kabira *et al.*, 2006$_a$; Gildemacher *et al*, 2007). Among the potato diseases, viruses are the most important and widespread and which result in reduction in quality and quantity of potatoes (Fletcher *et al.,* 1996; Were, 1996; Olubayo *et al.,* 2002; Biniam and Tadesse, 2007). Virus diseases can cause yield reduction of up to 90%, in addition to loss of quality of tubers (Salazar, 1996; Mih and Atiri, 2000).

High incidence of virus diseases and their aphid vectors have been reported in Kenya (Olubayo *et al.*, 2002). The viruses that have been detected in seed potato from farmers' stores are potato virus potato leaf roll virus, potato virus Y, potato virus S, potato virus A, potato virus X and potato virus M (Were, 1996; Kibaru, 2003; Machangi, 2004; Munyua, 2006; Nyaga, 2008). These viruses are transmitted through infected tubers while aphids are important vectors that transmit the diseases within seasons (Raman, 1985; CIP, 1996; Mih and Atiri, 2000; Radcliffe and Ragsdale, 2002). The most important and efficient aphid species is *Myzus persicae,* which transmits PRLV in a persistent manner (Raman, 1985; Jayasinghe, 1988; Jones, 2003). Other important aphids infesting potato in Kenya include *Macrosiphum euphorbiae, Aphis gossypii, Rhopalosiphum maidis, Aulacorthum solani* and *Aphis fabae* (Kibaru, 2003; Muindi, 2008; Muthomi *et al.*, 2009). The capacity and the knowledge of farmers to manage the viruses and control of aphids is limited resulting in high transmission of the viruses diseases in the (Nyaga, 2008). Therefore the objective of the study is to establish farmers' seed production practices in the main potato producing districts, and to determine levels and incidence of potato viruses in the farmers' produced seed potato.

3.2 Materials and methods

3.2.1 Survey and sample collection

A formal survey was carried out in six major potato growing districts which included Imenti North, Meru Central, Nyandarua South, Nyeri North, Nakuru North and Narok North. In each district four agro-ecological zones where potatoes are mainly grown were covered (Table 3.1and 3.2). Twenty small scale farmers from each district were randomly selected with the assistance of the agricultural extension officers in the district and a structured questionnaire was administered to each farmer (Appendix 2). The information obtained included land sizes, land area under potato, varieties of potato grown, source of seed potato, pests and diseases of potatoes, pests and diseases management practices, knowledge on potato viruses and aphids, harvesting practices, storage practices, potato markets and yield. One kilogram sample of seed tubers was collected from each farmer for virus serological analysis.

Survey was also conducted in twelve potato retail markets namely Meru, Nanyuki, Naivasha, Nyahururu, Narok, Ntulele, Bahati, Nakuru, Nyeri, Karatina, Kangemi and Githurai. The first ten markets are distributed within the six potato growing districts where the potatoes are grown, while Kangemi and Githurai obtain their potato from all parts of the country. In each market, five traders were randomly selected and a questionnaire administered to obtain information on source of potato, varieties sold, whether they sell seed potato and cost of seed potato (Appendix 3). One kilogram of seed potato was collected from each trader interviewed.

Table 3.1: Agro-ecological zones where survey was carried out during 2008 growing season

District	Division(s)	Agro-ecological zones
Nakuru North	Ndundori, Bahati	LH3, UH2, UH3, LH2
Narok North	Olkurto	LH2, LH3, UHI, UH2
Imenti North	Timau	LH3, LH4, UH2, UH3
Meru Central	Kibirichia	LH3, UH2, UH3, UH4
Nyeri North	Kieni East	LH3, UHI, UH2, UH3
Nyandarua South	Kinangop North	LH3, LH4, UH2, UH3

UH1-Upper highland 1, UH2-Upper highland 2, UH3-Upper highland 3, LH2- Lower highland 2, LH3-Lower highland 3, LH4-Lower highland 4

Table 3.2: Characteristic of agro-ecological zones where survey was carried out

Agro-ecological zone	Altitude (m)	Temperature (°C)	Annual rainfall (mm)	Growing season (Days)
UH1 Sheep and Dairy zone	2400 – 3000	10.0 - 14.6	1150 – 1600	350 – 360
UH2 Pyrethrum-Wheat zone	2400 – 3000	10.0 - 14.6	450 – 750	290 – 340
UH3 Wheat-barley zone	2370 – 2430	13.7 – 14.7	800 – 1100	220 – 280
LH2 Wheat(Maize)-Barley zone	1830 – 2100	14.5 – 16.6	900 – 1050	310 – 330
LH3 Wheat/(Maize)-Barley zone	2250 – 2280	15.0 – 15.2	800 – 950	210 – 220
LH4 Cattle-sheep-Barley zone	2190 – 2280	15.0 – 15.6	800 – 900	200 – 210

Source: Jaetzold, et al., 2006

3.2.2 Determination of types and amounts of viruses in potato tubers

The samples were treated with sprouting hormone, Citishooter© and sprouted in a well ventilated store for a period of between 3-4 weeks. Viruses in tubers were determined in sprouts by Double Antibody Sandwich Enzyme-Linked Immunosorbent Assay (DAS-ELISA) method as described by Clark and Adams (1977) and CIP (2007) at National Agricultural Research Laboratories at Kabete. The DAS-ELISA kit was obtained from the International Potato Center (CIP). All the six viruses were simultaneously assayed for PLRV, PVM, PVX, PVY, PVS and PVA.

Four to five tuber sprouts (0.5 g) per sample were extracted into 2.0ml of the extraction buffer (4.0g PVP-40000, 2.0g egg albumin) (Appendix 4). Extraction was done using a rolling stick by pressing on a flat surface. Each microtire plate was coated with 10 ml of coating buffer (0.2g Na_2CO_3, 0.44g $NaHCO_3$, 0.03gNaN_3, and 30.0 ml distilled water) with 35µl of antibody (IgG) of the virus to be detected and the process was done for all the six viruses. Each well was then coated with 100 µl of the coating solution and plates sealed with masking tape and incubated at 37 ^{0}C for 3-4 hours. The plates were then emptied and dried immediately using an absorbent paper. Each well was then filled with Phosphate buffer saline-tween (8.0g NaCl, 0.2 g $KH2PO_4$, 1.15 g Na_2HPO_4, 0.2g KCL, 0.195 g NaN_3, 1.0 litre distilled water) and soaked for three minutes and drained (Appendix 4). The procedure was repeated three times until the plates were clean. One hundred microlitre of the ground sample was extrcted then put into the wells and the plates sealed with masking tape and incubated in refrigerator at 4 ^{0}C overnight.

The plates were then washed with the PBS-T. A conjugate solution was prepared by mixing 35 μl of respective conjugate antiserum (IgG-A'p) with 10 ml of conjugate buffer (0.4 g PVP-40000, 0.04 gm egg albumin). Then 90 μl of conjugate solution was added to each well and incubated at 37 ^{0}C for 4 hours. The plates were then drained and washed four times with PBS-T. A substrate solution was prepared through dissolving one tablet substrate tablet (17.46 ml Diethanolamine, 9.6 ml distilled water, 2.4 ml HCL (37%) in 10 ml of substrate buffer then 80 μl of the substrate solution was added to each well of the plate an the plates were than left for 30-60 minutes at room temperature for reaction to take place. A positive reaction was indicated by development of a yellow colour. Colour intensity was determined by spectrophotometer at 405 nm wavelength according to the relationship $x \geq \bar{\imath} + 0.05$, where x = positive sample, $\bar{\imath}$ = average value of healthy controls and 0.05 = standard deviation.

3.2.3 Data analysis

Data analyzed using the Statistical Package for Social Science (SPSS) soft ware package to determine frequencies and percentages. Data on virus incidence and titre was subjected to analysis of variance using GenSat computer software package (Lawes Agricultural Trust Rothamsted Experimental Station, 2007). Separation of means was by the Fisher's protected Least Significant Difference (LSD) test at 5% confidence interval.

3.4 Results

3.4.1 Seed production practices among small scale farmers Potato land sizes

3..4.1.1 Potato land sizes

The size of farms differed in the districts where the survey was conducted. Most of the farmers had 2-5 acres of land in all the districts (Table 3.3). Majority of the farmers (38.3%) had 2-5 acres and 2.5% had less than one acre. Small land parcels of less than an acre were most prevalent in Nyeri North and Meru Central while more farmers in Narok North had land parcels of more than 10 acres. Majority of farmers (40.8%) grew were growing potatoes on more than one acre (Table 3.3). Majority of the farmers in Nyeri North who grew potato on land parcels of 0.125 and 0.5 acres were from while farmers in Imenti North grew potatoes on land parcel of 0.5-1.0 acre. The highest proportion of farmers who grew potatoes on more than one acre of land was in Nyandarua South while the lowest was in Nyeri North.

3.4.1.2 Source of seeds

The survey revealed that all the farmers used own seeds while, the least number of farmers obtained seed from KARI, Tigoni (1.6%) (Table 3.4). Farmers also sourced seed potato from the markets and from neighbours. The highest percentage of farmers who were purchasing potato seed from the markets was in Nyeri North, while the highest percentage of farmers purchasing seed for neighbours was in Narok North. Farmers who purchased seeds from KARI, Tigoni were in Nyandarua South and Meru Central. Farmers in Nyandarua South, Narok North, Imenti North and Meru Central had sourced seeds from farmers' groups.

Table 3.3: Frequency (%) of farmers owning different land sizes in different potato growing districts

Total farm acreage	Nyeri North	Nyandarua South	Nakuru North	Narok North	Imenti North	Meru Central	Mean
Less than 1 acre	5.0	0.0	0.0	0.0	0.0	10.0	2.5
1 – 2 acres	15.0	5.0	5.0	0.0	30.0	30.0	14.2
2-5 acres	50.0	25.0	60.0	10.0	45.0	40.0	38.3
5-10acres	25.0	30.0	35.0	25.0	20.0	20.0	25.8
10 acres	5.0	45.0	0.0	65.0	5.0	0.0	20.0
Potato plot acreage							
0.125 and 0.5 acres	40.0	25.0	35.0	30.0	10.0	30.0	28.3
0.5-1.0 acre	45.0	5.0	15.0	15.0	65.0	40.0	30.8
More than 1 acre	15.0	70.0	50.0	55.0	25.0	30.0	40.8

Table 3.4: Source of seed potato (percentage of farmers) for small scale potato farmers in different districts

Source of seeds	Nyeri North	Nyandarua South	Nakuru North	Narok North	Imenti North	Meru Central	Mean
Own seeds	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Local market	55.0	25.0	50.0	25.0	40.0	30.0	37.5
Buy from neighbour	35.0	25.0	40.0	55.0	30.0	30.0	35.8
Farmers' group	0.0	5.0	0.0	5.0	5.0	5.0	3.3
KARI-Tigoni	0.0	5.0	0.0	0.0	0.0	5.0	1.6

3.4.1.3 Potato variety preference by farmers and traders

Most traders across all the markets preferred Nyayo and Tigoni except in Karatina, Meru and Ntulele where the traders preferred other varieties (Table 3.5). Kerrs pink was most preferred variety in Meru while Asante was most preferred in Nanyuki with up to 80% preference. Different regions differed in type of potato varieties preferred by farmers (Table 3.6). Similar variation was observed among the farmers. The most preferred variety across the districts was Tigoni with up to 50% of the farmers planting the variety. High yielding was the most considered characteristic by farmers in the choice of variety to plant (Table 3.7). However market demand and storability were the least considered by farmers in most districts. Other characteristics considered by farmers in choice of varieties to plant were red skin colour, early maturity and disease resistance.

Table 3.5: Frequency (%) of traders in different markets who preferred different varieties of Irish potatoes

Variety	Ba	Gi	Ka	Kar	Me	Na	Nak	Nar	Nt	Nya	Nye	Nan	Mean
Nyayo	40	20	20	20	0	80	20	40	40	40	20.0	0.0	28.0
Tigoni	40	20	40	0	0	20	40	40	0	60	20	0	23
Kerrs pink	0	40	20	20	80	0	0	0	0	0	20	20	16
Asante	0	20	20	20	0	0	0	0	0	0	0	80	12
Pima suti	0	0	0	0	0	0	40	20	40	0	0	0	8
Mwezi moja	20	0	0	20	0	0	0	0	20	0	40	0	8
Kibururu	0	0	0	20	0	0	0	0	0	0	0	0	2
Ngure	0	0	0	0	20	0	0	0	0	0	0	0	2

Ba= bahati; Gi= Githurai; Ka= Kangemi; Kar= Karatina; Me= Meru; Na= Naivasha; Nak= Nakuru; Nar= Narok; Nt= Ntulele; Nya= Nyahururu; Nye= Nyeri; Nan=Nanyuki

Table 3.6: Proportion (%) of farmers' in different districts who preferred different potato varieties

Variety	Nyeri North	Nyandarua South	Nakuru North	Narok North	Imenti North	Meru Central	Mean
Tigoni	30.0	30.0	20.0	50.0	15.0	10.0	25.8
Kibururu	0.0	0.0	0.0	0.0	45.0	25.0	11.6
Mwezi moja	15.0	0.0	45.0	0.0	0.0	0.0	10.0
Asante	15.0	5.0	0.0	0.0	15.0	20.0	9.0
Pima suti	15.0	0.0	15.0	20.0	0.0	0.0	8.3
Nyayo	10.0	10.0	0.0	30.0	0.0	0.0	8.3
Changi	0.0	40.0	5.0	0.0	0.0	0.0	7.5
Komesha	0.0	0.0	15.0	0.0	0.0	20.0	5.8
Kerrs pink	15.0	0.0	0.0	0.0	10.0	0.0	4.2
Arika	0.0	0.0	0.0	0.0	5.0	20.0	4.2
Ngure	0.0	0.0	0.0	0.0	15.0	0.0	2.5
Dutch Robjin	0.0	10.0	0.0	0.0	0.0	0.0	1.6
Kenya karibu	0.0	0.0	0.0	0.0	0.0	5.0	0.8
Tana	0.0	5.0	0.0	0.0	0.0	0.0	0.8

Table 3.7: Frequency (%) of farmers in different districts who preferred different potato characteristics

Variety characteristic	Nyeri North	Nyandarua South	Nakuru North	Narok North	Imenti North	Meru Central	Mean
High yielding	70.0	85.0	90.0	80.0	30.0	95.0	75.0
Disease resistance	30.0	5.0	0.0	5.0	25.0	0.0	10.8
Early maturing	0.0	0.0	10.0	5.0	10.0	5.0	5.0
High yielding/red color	0.0	0.0	0.0	0.0	35.0	0.0	5.8
Storability	0.0	10.0	0.0	5.0	0.0	0.0	2.5
High market demand	0.0	0.0	0.0	5.0	0.0	0.0	0.8

3.4.1.4 Agronomic practices in potato production

Different agronomic practices were being practiced by farmers during the growing of potatoes (Table 3.8). A lower percentage of farmers (49.2%) had seen aphids compared to 50% who had seen virus diseases symptoms in the districts. Majority of the farmers who had seen aphids were in Nyandarua South while the least number of farmers who had seen aphids were in Nakuru North. Sixty five percent of farmers in Nyandarua South and Imenti North had seen virus symptoms as compared to 35% in Narok North.

Farmers in the districts were using chemical, rotation and positive selection in management of pests and diseases (Table 3.8). Chemical control of pests and diseases was the most preferred management strategy with a prevalence of 42.5% while positive selection was the least preferred (4.2%) across the districts. The highest proportion of farmers using rotation were in Nakuru .

Table 3.8: Frequency of farmers (%) using different pest and disease management practices in potato production in different districts

Crop protection measures	Nyeri North	Nyandarua South	Nakuru North	Narok North	Imenti North	Meru Central	Mean
Seen virus symptoms	40.0	65.0	45.0	35.0	65.0	50.0	50.0
Seen aphids	45.0	70.0	40.0	40.0	45.0	55.0	49.2
Use chemicals	50.0	30.0	35.0	50.0	35.0	55.0	42.5
Use rotation	10.0	5.0	35.0	35.0	10.0	5.0	16.7
Positive selection	0.0	15.0	0.0	10.0	0.0	0.0	4.2

and Narok North while positive selection was practiced by farmers in Nyandarua South and Narok North. Other agronomical practices carried out by farmers were fertilization, manuring, dehaulming, grading and sprouting of seed potatoes (Table 3.9). Use of DAP, NPKs and manure within the districts varied, with most of the farmers (72.5%) applying manure. Ninety percent of the farmers in Nyandarua South and Narok North were using DAP to grow potatoes while farmers in Imenti North preferred using NPKs with a prevalence of 60%. The proportion of farmers who were grading potatoes was 80.3% while 85% of farmers were sprouting seeds across the districts. Only a small percentage (3.3%) of farmers in the districts was dehaulming potatoes before harvesting. Grading of potatoes was being carried out by all the farmers in Imenti north while sprouting of seeds was a common practice with farmers in Nyandarua South and Meru Central

Table 3.9: Frequency (%) of farmers using varying agronomical practices in potatoes in different districts

Activity	Nyeri North	Nyandarua South	Nakuru North	Narok North	Imenti North	Meru Central	Mean
Use DAP fertilizer	45.0	80.0	90.0	90.0	35.0	50.0	65.0
Use NPKs	10.0	5.0	0.0	0.0	60.0	30.0	17.5
Use manure	70.0	95.0	55.0	40.0	85.0	90.0	72.5
Dehaulm	5.0	0.0	5.0	5.0	5.0	0.0	3.3
Grading tubers	75.0	90.0	75.0	75.0	100.0	70.0	80.3
Sprout seed	90.0	100.0	80.0	60.0	80.0	100.0	85.0

3.4.1.5 Potato yield and storage practices

Majority of the farmers (46.7%) were realizing less than 2 tons/ha of potatoes, while very few farmers (5.3%) were getting more than 5 tons/ha across the districts (Table 3.10). The highest percentage of farmers harvesting 3-5 tons/acre was in Imenti North while the least number of farmers was in Narok North and Meru Central. Within the districts, 55% of farmers were storing ware potatoes before selling with the majority of the farmers storing ware potatoes being found in Nyeri North and Nyandarua South (Table 3.11). The most preferred storage structure across the districts was wooden structure with a preference of 59.2%. Most of the farmers using wooden structures were in Meru North, with the least number of farmers were in Nakuru North. The highest percentage of farmers (79.2%) was storing seed potato for a period of between one and two months before planting them with the lowest percentage of farmers storing seed potato for less than one month in the districts.

Table 3.10: Frequency (%) of farmers and their corresponding yield (ton/acre) of potatoes different districts

Yield per acre	Nyeri North	Nyandarua South	Nakuru North	Narok North	Imenti North	Meru Central	Mean
Less than 2	65.0	20.0	65.0	75.0	15.0	40.0	46.7
2-3	30.0	50.0	15.0	15.0	35.0	40.0	30.8
3-5	15.0	20.0	20.0	10.0	35.0	10.0	18.3
Above 5	0.0	10.0	0.0	0.0	15.0	10.0	5.8

Table 3.11: Frequency (%) of farmers in different districts who practice different storage practices

Storage practices	Nyeri North	Nyandarua South	Nakuru North	Narok North	Imenti North	Meru Central	Mean
Store ware potato	80.0	80.0	15.0	70.0	65.0	20.0	55.0
Store in wooden structure	40.0	70.0	60.0	45.0	65.0	75.0	59.2
Store in sacks	20.0	0.0	5.0	0.0	15.0	25.0	10.8
Store underground	20.0	0.0	0.0	20.0	5.0	0.0	7.5
Store seed < 1 month	5.0	0.0	0.0	0.0	0.0	0.0	0.8
Store seed 1-2 months	85.0	75.0	95.0	65.0	80.0	75.0	79.2
Store seed > 2 months	10.0	25.0	5.0	35.0	20.0	25.0	20.0

3.4.2 Occurrence of potato viruses in farmers' produced seed potato

3.4.2.1 Incidence and levels of potato viruses in seed tubers from farmers' stores

Potato viruses were detected in seed potato tubers samples from all the six districts surveyed. The potato viruses detected were potato leaf roll virus (PLRV), potato virus A (PVA), potato virus M (PVM), potato virus S (PVS), potato virus X (PVX) and potato virus Y (PVY). Potato virus S had the highest virus incidence in the districts (Table 3.14). Other virus that was in the districts was prevalent PLRV, and PVY and the least prevalent were PVA, PVM and PVX. There were significant ($p \leq 0.05$) differences among the districts in percentage incidence of all the potato viruses, except PVA and PVY. Potato leaf roll virus was highly prevalent in Nyeri North, Nyandarua South, Narok North abd Nakuru North (upto 100%) while Potato virus A was highly prevalent in Nyandarua South (upto 65%). Potato virus S was highly prevalent in Meru Central, Nakuru North, Narok North, Imenti North and Nyandarua South (upto 100%). while PVM was highly prevalent in Nyeri North (Upto 75%). Potato virus X was highly prevalent in Imenti North and Meru Central (upto 80%), while PVY was highly prevalent in Nyandarua South (upto 100%).

The highest virus titres in potato tubers collected from the farmers' stores was for PVS, PVX and PVM while the lowest was for PLRV, PVA and PVY (Table 3.13). There were significant ($p \leq 0.05$) differences among the districts in virus titres of all the viruses except, PLRV and PVY. Highest virus titre for PVM was in seed potato from Nyandarua South while highest virus titre for PVS was in samples from Imenti North and Nyandarua South. Highest virus titre for PVX was in samples collected in Imenti North while highest virus titre of PVY was in samples from Nyandarua South.

Table 3.12: Percentage (%) incidence of potato viruses collected from the farmers in different districts during the 2008 growing seasons

District	PLRV	PVA	PVM	PVS	PVX	PVY
Meru Central	100.0	40.0	5.0	100.0	80.0	25.0
Nyeri North	100.0	35.0	75.0	95.0	25.0	90.0
Nakuru North	100.0	45.0	30.0	100.0	40.0	90.0
Narok North	100.0	15.0	20.0	100.0	10.0	90.0
Imenti North	65.0	40.0	5.0	100.0	80.0	25.0
Nyandarua South	15.0	65.0	20.0	100.0	35.0	100.0
$LSD_{(P\leq0.05)}$	27.1	Ns	23.5	Ns	29.9	29.8
CV (%)	10.8	14.5	45.2	1.7	22.5	6.9

Table 3.13: Mean virus titre in potato tubers collected from farmers' stores in various districts during 2008 growing seasons

District	PLRV	PVA	PVM	PVS	PVX	PVY
Meru Central	0.08	0.08	0.01	0.45	0.06	0.01
Nyeri North	0.13	0.04	0.02	0.37	0.04	0.01
Nakuru North	0.06	0.02	0.01	0.35	0.07	0.01
Narok North	0.04	0.01	0.01	0.21	0.04	0.01
Imenti North	0.03	0.08	0.19	0.77	0.97	0.01
Nyandarua South	0.03	0.07	0.20	0.77	0.51	0.02
$LSD_{(P\leq0.05)}$	Ns	0.03	0.05	0.22	0.65	Ns
CV (%)	41.3	20.3	24.9	19.6	58.3	63.5

Ns denotes not significant ($p\leq0.05$). PLRV- potato leaf roll virus, PVA- potato virus A, PVM- potato virus M, PVS- potato virus S, PVX- potato virus X, PVY- potato virus Y

3.4.2.2 Incidences and levels of potato viruses in tubers from retail markets

Viruses detected in potato tubers from retail markets were potato leaf roll virus (PLRV), potato virus A (PVA), potato Virus M (PVM), potato Virus S (PVS), potato virus X (PVX) and potato virus Y (PVY) (Table 3.14). The most prevalent were PLRV, PVS and PVY while the least prevalent were PVA, PVM and PVX (Table 3.12). There were significant ($p \leq 0.05$) differences among the retail markets in the incidence of all the potato viruses, except PVY. Potato leaf roll virus (PLRV) was highly prevalent in Bahati, Kangemi, Karatina, Nakuru, Ntulele and Nyeri (upto 100%) while PVY was prevalent Kangemi and Karatina (upto 60%). Potato virus M was highly prevalent in Githurai, Kangemi, Karatina, Meru, Naivasha, Nanyuki, Nyahururu and Nyeri (upto 100%) while PVS was highly prevalent in all the retail markets. Potato virus A was highly prevalent in Githurai, Kangemi, Karatin, Meru, Naivasha, Nanyuki, Nyahururu and Nyeri (upto 100%) while PVX was highly prevalent in Kangemi, Karatina and Nyeri (upto 100%), There were significant ($p \leq 0.05$) differences among the retail markets in percentage incidences of all viruses except PVY.

Highest virus titres were for PVS, PVM and PVA while lowest virus titres were for PLRV, PVX and PVY (Table 3.15). There were significant ($p \leq 0.05$) differences among retail markets in virus titres of all viruses except PVY in tubers collected from the retail markets. The highest virus titre of PLRV was in tubers collected from Kangemi while the highest virus titre of PVA was in potato seed collected from Nanyuki. Highest virus titre of PVM was in samples collected in Nyahururu while highest virus titre of PVS was in tubers collected from Kangemi. Highest virus titre of PVS was in samples collected in Nanyuki while highest virus titre of PVY was in samples collected from Githurai.

Table 3.14: Percentage (%) incidence of different viruses in potato tubers samples from various retail markets in 2008 growing seasons

Market	PLRV	PVA	PVM	PVS	PVX	PVY
Bahati	100.0	0.0	0.0	100.0	20.0	0.0
Githurai	80.0	100.0	100.0	100.0	80.0	40.0
Kangemi	100.0	100.0	100.0	100.0	100.0	60.0
Karatina	100.0	100.0	100.0	100.0	100.0	60.0
Meru	0.0	100.0	100.0	100.0	40.0	0.0
Naivasha	0.0	100.0	100.0	100.0	40.0	0.0
Nakuru	100.0	0.0	20.0	100.0	40.0	0.0
Nanyuki	0.0	100.0	100.0	100.0	80.0	40.0
Narok	80.0	80.0	20.0	100.0	80.0	20.0
Ntulele	100.0	0.0	80.0	40.0	40.0	0.0
Nyahururu	20.0	100.0	100.0	100.0	20.0	40.0
Nyeri	100.0	100.0	100.0	100.0	100.0	40.0
$LSD_{(P \leq 0.05)}$	28.3	16.5	29.3	20.2	53.9	Ns
CV (%)	10.7	5.1	4.9	4.8	22.6	47.1

Ns denotes not significant ($p \leq 0.05$). PLRV- potato leaf roll virus, PVA- potato virus A, PVM- potato virus M, PVS- potato virus S, PVX- potato virus X, PVY- potato virus Y

Table 3.15: Mean virus titre in potato seed tubers collected from retail markets during 2008 growing seasons

Market	PLRV	PVA	PVM	PVS	PVX	PVY
Bahati	0.12	0.0	0.0	0.40	0.01	0.0
Githurai	0.16	0.10	0.10	0.80	0.66	0.12
Kangemi	0.24	0.10	0.08	0.83	0.37	0.03
Karatina	0.14	0.06	0.05	0.66	0.24	0.07
Meru	0.0	0.20	0.03	0.69	0.37	0.0
Naivasha	0.0	0.14	0.02	0.66	0.59	0.0
Nakuru	0.08	0.0	0.0	0.29	0.01	0.0
Nanyuki	0.0	0.25	0.12	0.62	1.00	0.04
Narok	0.06	0.04	0.01	0.25	0.02	0.0
Ntulele	0.14	0.0	0.03	0.14	0.01	0.01
Nyahurruru	0.04	0.10	0.18	0.56	0.01	0.01
Nyeri	0.20	0.08	0.05	0.78	0.24	0.04
$LSD_{(P\leq 0.05)}$	0.08	0.08	0.05	0.24	0.60	ns
CV (%)	22.8	17.4	12.8	12.8	81.8	103.7

Ns denotes not significant ($p\leq 0.05$). PLRV- potato leaf roll virus, PVA- potato virus A, PVM- potato virus M, PVS- potato virus S, PVX- potato virus X, PVY- potato virus Y

3.5 Discussion

3.5.1 Seed production practices among small scale farmers

The majority of the farmers owed land between 2-5 acres and highest percentage of farmers were growing potatoes on more than one acre of land. This is in agreement with Nyaga (2008) findings that majority of the farmers owned 1-5 acres while most of the farmers were growing potatoes on more than one acre in Njabini and Limuru. The difference in the total land acreage may be attributed to different land size holding in each district. However despite the low acreage the proportion of land allocated for potato growing was high compared to other enterprises at the farm. Kabira *et al.* (2006_a) reported that potatoes are gaining prominence even in areas that were traditionally for cereals. The shifting of farmers to growing of potato may be attributed to its short growing period and hence the farmer can grow and harvest the crop even when the rainfall is erratic (Nganga and shileder, 1982)

A small percentage of farmers were using crop rotation in the management of pests and diseases which have other benefits such as soil fertility improvement. This is in agreement with findings by KARI (2008) who reported adoption of other control measures in addition to conventional chemical control. The low adoption of rotation as pest and disease control measure may be due to small land holding that was also being used to grow other crops and putting up homestead which left very little land to practice crop rotation (Kidanemarim *et al.* 1999). The farmers also depended on the sale of the potatoes for income generation which make them to have a crop of potato every season as reported by CIP (2008), and MOA ($2007_{a,}$).

Most farmers were found to use own seeds, while others were purchasing from the markets and from other farmers within their areas. The finding is in agreement with Crissman (1989), Kinyae *et al.* (1994; MOA, 2008_a) who reported that majority of the farmers were using seeds produced from the informal sectors. This is due to inadequate supply of certified seeds which was also inaccessible to most of the farmers (Kinyae *et al.* 1994; MOA, 2008). The certified seed is also expensive beyond the reach by majority of small scale farmers (Ayieko and Tschirley, 2006). Lack of certified seed potato of popular varieties from the research station may also contribute to farmers using their own seed potatoes. Some farmers were also purchasing seed potato seeds from farmers' groups which can be attributed to presence of organized producer groups in the districts (KARI, 2008). Farmer groups can be used to multiply clean seed potatoes from research stations especially for the preferred varieties (Kidanemarim *et al.*, 1999).

Preference of potato varieties differed within the districts although majority of the farmers preferred growing Tigoni across the district. The high preference of Tigoni and Asante varieties may be attributed to their high yield potential and some resistance to diseases (Munyua 2006). KARI Tigoni has also been promoting these two varieties for a long period (Kabira *et al.*, 2006_a). Different regions had been found to prefer growing non-certified seed potato of local variety prefer growing local varieties which had no certified seeds. This may be attributed characteristics associated with these varieties like mashing quality and shorter growing season. Such varieties can be exploited by thorough cleaning and then multiplication by groups for sale to potato farmers. Majority of the farmers preferred varieties that are high yielding and this agrees with Crissman (1989) and Kibaru (2003) who found that majority of farmers choose varieties based on yields. Other characteristics that were considered by farmers included disease resistance, long storability and skin colour in some region (Kabira, 2000; KARI, 2007, Walingo *et al.*, 2005).

About half of the farmers included in the survey had seen aphid and virus disease symptoms. This contract finding by Nyaga (2008) who reported that up to 22.5% of farmers had seen aphids and knew the virus symptoms. The high percentage of farmers who had seen aphids and virus symptoms may be as a result of awareness created by KARI, Universities and the Ministry of Agriculture (KARI, 2008, Gildemacher *et al.*, 2007). However the response from the farmers was very low compared to the findings by Olubayo *et al.* (2004) who reported virus incidence of aphids and virus diseases was up to 100%.

Chemical control was most preferred by farmers as compared to the other control options. KARI (2008) and Kinyua *et al*, (2001) reported high use of chemicals for the control of blights due to their devastating effect. This is because of the cold and wet weather where the potatoes are grown, which is favorable for the multiplication of the late blight fungus (MOA, 2007). Very few farmers were found to use positive selection as an option to reduce virus disease incidence. The low uptake may be due to slow introduction and the group based approach which locks individual farmers out (Gildemacher *et al.*, 2007). The study found a low (3.3%) were dehauming Irish potatoes. The low number of farmers dehaulming potato before harvest may be attributed to lack of knowledge on the importance of dehaulming. Dehauming is an important agronomical practice in realizing hardened tubers of high quality. Farmers harvest mmature harvesting of ware potatoes to maximize on high prices offered before the beginning of the main potato harvesting period. Dehaulming is an important agronomical practice which can be emphasized to potato farmers due to its importance in getting quality tubers as reported by Kabira *et al.* (2006_a). Zhu *et al.*, (2006) and Sigvald, (2004) found out that dehaulming can be applied as a management tool for viruses that are introduced into seed potato tubers late in the season.

Storing of ware tuber grades after harvesting was not a very common practice with many farmers. The survey finding is in agreement with similar work done by Walingo *et al.*, (2004) who found that only some farmers were storing ware potatoes. This may be due to lack of storage facilities which are expensive to construct and perishability of potatoes. Improper storage of potatoes for long period also leads to loss of weight and quality of tubers which may reduce the market value of the crop. The bulkiness of potatoes and also the immediate need of cash by farmers forces the farmers to sell off the crop at harvest time as reported by to sale at farm gate result to farmers seeing no need store the ware potato a reported by MOA/PSDA, (2007). However, the seasonality of the potato tubers requires them to be stored to be stored to regulate the movement of the crop in the market to stabilize the prices resulting to improvement of farmers' incomes (MOA, 2005).

The storage facilities that were common at the farm were wooden structures, sacks and also underground. Majority of the farmers store were storing seed after they harvest for 1-2 months. The storing of seed is done to await the rains that usually come after 2-3 months after the potatoes are harvested. Farmers' yields were found to be very low, with the majority (77.5%) producing less than 30 bags compared to 100 bags per acre by KARI (KARI, 2007, Kabira *et al.*, 2006 MOA, 2008_a). The low yields obtained farmers is low due to low use of farm inputs, poor agronomical practices and use of low quality seeds (Ayieko and Tchirley, 2006; Machangi *et al.*, 2004; MOA_a, 2008; Nyoro, 2000).

3.5.2 Occurrence of potato viruses in farmers' produced seed potato

The viruses that were detected in the potato samples were potato leaf roll virus (PLRV), potato virus A (PVA), potato virus M (PVM), potato virus S (PVS), potato virus X (PVX) and potato virus Y (PVY) The result of the survey indicate that viruses are prevalent in potato growing areas (Machangi *et a,*, 2004, Kang *et al.* 2007; Khatri and Shrestha, (2004). This agrees with findings of Fletcher *et al.* (1996) and Nyaga, (2008) who detected all the six viruses in potato tubers collected from the farmers. The most encountered virus in the samples from farmers' store and from retail markets was PVS. Machangi (2004) reported PVS as the most prevalent virus in Tigoni while Nyaga (2008) found out that PVS and PLRV were the most encountered viruses in Tigoni and Njabini. The high incidences of the viruses in the main potato growing may be due farmers recycling contaminated seed potatoes and failure to control the aphid vectors. Another reason for the high virus disease incidence may be due to availability of alternative crop or weed hosts within or in nearby farms which enable the vector to breed throughout the year.

The farmers' seeds were infected with more than one virus. This is in agreement with the findings by Fletcher *et al.*, (1996), Machangi, *et al.,* (2004), Kang *et al.* (2007) found potato having multiple infection with the viruses. Jayasinghe (1988) reported a yield loss of up to 90% in potatoes due to PLRV. This may be due to different species of aphids being present in the farmers' fields which transmit these viruses. The presence of more severe viruses (PLRV and PVY) in combination with less severe viruses (PVA, PVS, PVX and PVM) at the farmers farms can result in more yield loss at the farm compared to loss by additive of each viruses found singly in potato (Biniam and Taddesse; Pourrahim and Farzadfar, 2007). Farmers have limited capacity to manage the virus disease and aphids at the farms (Kibaru, 2003; Nyaga, 2008). Farmers should be encouraged to produce disease free seed potato to increase production through cheap and easily adoptable measures (Mathu *et al.*, 2004)

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CHAPTER 4: EFFECT OF MAIZE BORDER CROP PLACEMENT ON APHIDS AND APHID-TRANSMITTED VIRUSES IN IRISH POTATO

3.1 Abstract

A field experiment was conducted at NPRC, Tigoni over two growing seasons to determine the effect of maize border crop placement on aphid population and aphid-transmitted virus diseases. Maize borders were planted at at 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 metres from the potato plots and the incidence of viruses and aphid population determined over the growth period. Aphid population was determined on leaves and water pan traps while virus infection was determined by visual symptoms. Virus titre was determined in tubers after harvest. Other data collected included virus titre plant height and tuber yield. The data obtained was analyzed using GenSat statistical software.

Placement of maize border up to 0.5m and 1.0m significantly reduced virus disease incidence by 43% and 48% during long rain season and short rain season respectively. However, the lowest aphid population was recorded in plots with placement distance of 1.0m. Yield of tubers harvested from plots with border placement distance at 0.5m was the lowest and had a yield reduction of unto 43% and 48%.

The result obtained show in this study indicated that placement of maize border crop can be used as a cultural method in the management of aphids and aphid-transmitted viruses. The most effective placement distance in control of viruses in seed potato was 1.0m. However determination on the number of seasons seed potato harvested from plots with maize border can be used before yields are reduced to uneconomical level need to be done.

4.2 Introduction

Viruses which are vectored by aphids are important diseases of Irish potatoes worldwide (Mih and Atiri, 2000). Potato leaf roll virus (PRLV), Potato virus Y (PVY), Potato virus S (PVS), Potato virus M (PVM), Potato virus A (PVA) and Potato virus X (PVX) are the most important viruses in potatoes in their effect on the yield as well as being widely distributed (Corral, 2001; Salazar, 2006). The viruses are also transmitted through infected tubers which is an important method of transmitting them from one season to another (Burhan, 2007; Mih and Atiri, 2000). Potato leaf roll virus is the most important virus in the world and it is persistently transmitted by *Myzus persicae* (Raman, 1985, Suranyi, 1996). Potato virus Y is second in importance, highly variable in nature and the virus is transmitted by several aphids in non-persistent manner (Harbert *et al.*, 2003; Jones *et al*, 2003; Baldauf *et al.*, 2006; Difonzo *et al*, 1996; Lorenzen *et al.*, 2006).

In most of the time it is the non colonizing aphids that are largely responsible for the spread of the non-persistently transmitted viruses (James and Falk, 2006). Important aphids identified infesting potatoes in the country include *Myzus persicae*, *Macrosiphum euphorbiae*, *Aphis gossypii*, *Aphis fabae, Aulacorthum solani* and *Rophalosiphum maidis (*Nderitu and Mueke, 1986; Kibaru, 2003; Machangi, 2004; Nyaga, 2008).

The insecticides have been ineffective in controlling PVY as compared to PLRV (Fereres, 2000; Zitter and Burrows, 2005). Use of barrier/borders is a simple cultural method that requires no specialized equipment as compared to use of chemicals. Use of border crops reduces the possibility of using chemical hence reducing the chemical residue in the tubers (Takada, 1995) Barrier/border crops have been used in management of the PVY which is transmitted in a non-persistent manner (Difonzo *et al*, 1996). In the non-persistently transmitted viruses the aphid acquires and loses the ability to transmit the virus within a very short time (Gray and Gildow, 2003; Suranyi R., 1999). Once the viruliferous alate aphid lands on the border crop it losses the virus during the brief probing session while trying to identify a suitable host (Fereres, 2000). The barrier crop thus act as a sink for the stylet borne viruses reducing the ability of the aphid to transmit the virus to the primary crop (Boiteau *et al.*, Hooks and Fereres, 2006; Halbert *et al*, 2003).

Wheat, sorghum, soybeans and potatoes have been as trap crops in potatoes to control *Acyrtosiphum pisum* (pea aphid) (Shelton and Badenes-Perez, 2006) in USA. Studies done in Kenya by Kibaru (2003) and Muindi (2008) showed that border crops are effective in lowering of virus titre and reducing the number of aphids in bordered potato crop compared to non bordered crop. The border crops used in the above studies were millet, sorghum, maize, wheat, garden peas and broad peas. Maize, sorghum and wheat were effective in reducing the aphid population and virus titre. Placement of border crops was done at 0.5 and 1.0m. However no study has been done to determine the effective distance for the placement of border crops. The objective of the study was to determine effective border crop placement distance in management of aphids and aphid transmitted viruses in seed potato.

4.3 Materials and methods

4.3.1 Experimental design and layout

Field experiments were conducted at the National Potato Research Centre (NPRC), KARI-Tigoni during the long rain season (March-August 2008) and short rain season (October 2008-February 2009). The treatment were placement of maize (*Zea mays*) border crop at varying distances (0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 metres) from the potato plots. The size of potato plot was 4.5 metres by 4.5 metres, with inter-row spacing of 75 cm and intra-row spacing of 30 cm. The border crop consisted of three rows of maize planted at 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 metres respectively from the potato plots. The border crop spacing treatments were laid out in randomized complete block design with three replications. One control plot was set up without a maize border crop during the first season. During the second season an additional plot was planted using seeds harvested from the first season control plot. The purpose of the second control was to investigate virus build up in successive season if the same seed is planted without any control measure being put in place. The distance between the blocks was two metres while that between the potato-border plots was one metre. Data collected included aphid population, potato plant height, virus disease incidence, virus titre and tuber yield.

4.3.2 Crop husbandry

Land preparation was done 3-4 three weeks before the planting commenced. Seed potatoes cv Tigoni was purchased from KARI-Tigoni while the other inputs were sourced from a reputable stockist. Hybrid 614 seed maize was planted at the onset of rains maize and then potatoes were planted three weeks after maize germinated. Planting of maize was done at inter-row spacing of 75 cm and an intra row spacing of 30cm. Fertilizer used was DAP (18-46-0) at a rate of 200 kg per hectare which was mixed thoroughly with the soil before planting took place. Potatoes were planted at a depth of 10cm and DAP used a rate of 500kg/ha.ith the sprouts facing up. The first weeding was done three weeks after the maize germinated. Earthing up was done on the 4^{th} and the 8^{th} week after the potato emerged. Fungal diseases were controlled using metalaxyl (Ridomil®) at a rate of 2.4 kg a.i per hectare and spraying was done at an interval of two weeks. Topdressing of maize was done on the 6^{th} week when the crop was at using CAN (27%N) at a rate of 200Kg/ha. Maize stalk borer was controlled on the 6^{th} week after germination using Bulldock granules at a rate of 4.0 gm a.i/ha. Dehaulming was carried out when the crop was at physiological maturity stage through lifting the haulms and then leaving the tubers well covered by the soil for two weeks before harvesting commenced. Harvesting was carried out using blunt sticks by lifting potato tubers from each hill.

4.3.3 Monitoring of aphid population

Monitoring of aphid population was done on leaves and yellow water traps. The apterous and alate aphids were monitored on potato leaves while alate aphids were also trapped in yellow water pan traps. Sampling of leaves was done weekly from the 3rd week after the potato emerged up to the time the crop was physiologically mature. Ten plants were selected randomly in each plot and then three compounds leaves were picked from top, middle and bottom from each plant. The three leaves sampled from each plot were put in a polythene paper and stored at $4^{o}C$ until aphids were identified. The yellow water traps were set up immediately the maize emerged The yellow water traps were placed at the centre of each potato plot at a height of one metre and an additional traps were placed at each of the four corners. Each water pan trap was half filled with water and a detergent was added to break the water surface tension.

The aphids caught in the water traps were collected by sieving the contents through a muslin cloth and the aphids were immediately persevered in universal bottles containing 70% ethyl alcohol. Counting and identification of the aphids from leaves and water pan traps were done at the Entomology Laboratory of the Department of Plant Science and Crop protection. The aphids identified under stereo dissecting microscope (X40 magnification) based on morphological features as described by Martin (1983) and Blackman and Eastop (2007) (Table 4.1). In the laboratory the aphids on leaves were brushed off using a camel brush while the ones from water traps were transferred in a petri dish.

4.3.4 Assessment of virus disease incidence

Monitoring of potato plants showing viral symptoms was carried out on a weekly basis from three weeks after crop emerges until the crop matured. Symptoms that were observed as indicative of presence of viruses were leaf roll, erectiveness, brittle leaves, feathery leaves, mild and severe mottling, and dwarfness. The number of plants showing virus symptoms was counted and the incidence was calculated as number of plants showing the symptoms in each plot expressed as a percentage of total number of plant observed. The area under disease progress curve (AUDPC) was calculated for each plot using the following formula from data obtained on percentage virus incidence (Sparks, et *al,*. 2008).

$$AUDPC = \Sigma[(Y_{i+1} + Y_i) (0.5) (T_{i+1} - T_i)]$$

where Y = disease incidence at time T, and i = the time of the assessment (in days numbered sequentially beginning with the initial assessment)

Three plants showing leaf roll and mosaic and were tagged in each plot on the eighth week after the crop emerged and additional three plants showing no viral symptoms were also tagged. At maturity the tagged plants were harvested separately and put in a well labeled khaki paper bag. At harvesting a representative sample having 6-8 tubers from each plot were sampled for serological assay. The tubers were sprouted in a well lit store for a period of 1- 2 months and the sprouts were analyzed for type and quantities of viruses by serological assay, double antibody sandwich enzyme-linked immunosorbent assay (DAS-ELISA) method as described in section 3.3.2.

Table 4.1: Features used to identify different aphids species

Species	Body color	Antennal tubercles	Siphunculi	Dorsal abdominal pigmentation
Myzus persicae	Green or olive green	Well developed with inner sides converging	Clavate	Always bears a dorsal black patch
Macrosiphum euphorbiae	Green	Well developed with inner margin diverging distally	Cylindrical or tapering	Absent and completely green
Aphis gossypii	Green, olive, yellow, orange or black	Less developed or absent		black transverse bars with no black patch
Aphis fabae	Black	Less developed	Short and same length with caudal	No abdominal marking
Rophalosiphum maidis	Blue-green, grey	Less developed		Dark strip in the middle

Source Martin (1983); Blackman and Eastop, 2000

4.3.5 Assessment of potato tuber yield

The tuber yield was determined at physiological maturity when the crop turned yellow. Dehaulming was done by carefully lifting the haulm and leaving the tubers well covered with soil. Harvesting was done two weeks after the dehaulming through lifting the tubers per hill separately. Harvesting of the tagged plants was done separately and yield determined for each. The harvested tubers from each plot were sorted out into ware (> 55mm), seed (25-55mm) and chatts (< 25mm) (Kabira *et al.*, 2006) and the number and weight of each grade was determined. Plant height was also measured for ten plants per plot selected randomly from the third week up to the time the potato crop was physiologically mature and this data was taken on a weekly basis.

4.3.6 Data analysis

The data was subjected to analysis of variance using GenSat computer soft ware package (Lawes Agricultural Trust Rothamsted Experimental Station, 2007). Separation of means was by the Fisher's protected Least Significant Difference (LSD) test at 5% confidence interval.

4.4 Results

4.4.1 Potato aphid population on leaves and water traps

4.4.1.1 Potato aphid population on leaves

Aphid species identified were *Macrosiphum euphorbiae, Myzus persicae*, *Aphis gossypii*, *Aphis fabae* and *Rophalosiphum maidis* (Table 4.2). More aphids recorded in the potato plots with no border crops than the bordered plots during both long and short rain seasons. During long rain season the most abundant aphid species was *Macrosiphum euphorbiae* while the least abundant while *Aphis fabae* was the least abundant. *Macrosiphum euphorbiae* and *Aphis fabae* constituted 35% and 4% respectively of the total aphid species. There were no significant ($p \leq 0.05$)

differences among the maize border placements in respect to aphid species and aphid population during long rain season. The lowest number of aphids was recorded in potato plot with maize borders placed at 1.0m from the potato crop. During short rain season the most abundant species was *Aphis gossypii* while *Myzus persicae* was the least abundant aphid species (Table 4.2). *Aphis gossypii* and *Myzus persicae* constituted 58% and 1% respectively of the total aphid species. There were significant ($p \leq 0.05$) differences in population of *Myzus persicae* and *Aphis gossypii* among maize border crop placements..

Peak aphid population was attained at the 11th week after potato emergence while the lowest aphid population was attained at the 9th week during the long rain season (Table 4.3). There were significant ($p \leq 0.05$) differences in the number of aphid among the different border placement distances on the 7th week in both seasons. During short rain season, peak aphid population was recorded at the 8th week after emergence while the lowest aphid population was recorded on the 4th week.

Table 4.2: Mean number of aphids per 100 potato leaves in potato plots with varying maize border placements during long and short rain seasons, 2008

Long rain season						
Border crop distance (m)	Me	Mp	Ag	Af	Rm	Total
No border	20.0	7.6	8.9	1.1	13.3	50.9
0.5	8.9	6.7	12.2	1.1	7.8	36.7
1.0	8.9	5.6	5.6	1.1	4.4	25.5
1.5	17.8	8.9	11.1	1.1	10.0	48.9
2.0	12.2	8.9	6.7	2.2	6.7	36.7
2.5	18.9	3.3	6.7	4.4	4.4	37.8
3.0	10.0	11.0	7.8	1.0	12.2	42.2
$LSD_{(P\leq0.05)}$	Ns	Ns	Ns	Ns	Ns	Ns
CV (%)	21	6.7	23.6	41.7	21.4	7.3

Short rain season					
Border crop distance (m)	Me	Mp	Ag	Rm	Total
No border	5.4	1.0	250.7	126.3	381.0
0.5	3.3	0.0	186.7	127.0	316.0
1.0	5.9	0.0	150.7	66.7	220.0
1.5	7.0	10.0	130.7	174.0	319.0
2.0	5.0	1.0	189.7	94.3	292.0
2.5	4.9	2.2	140.0	97.7	244.0
3.0	5.2	0.0	140.7	132.3	276.0
$LSD_{(P\leq0.05)}$	NS	8.3	69	NS	NS
CV (%)	18.4	58.1	21.5	26.8	21.5

M.e = *Macrosiphum euphorbiae*; M.p = *Myzus persicae*; A.g = *Aphis gossypii*; A.f =*Aphis fabae;*R.m = *Rophalosiphum maidis* ns- Denotes not significant at ($P\leq0.5$). Data collected on 30 leaves extrapolated for 100 leaves

Table 4.3: Variation over time in the mean number of aphids per 100 leaves in potato plots with varying maize border crop placement distances at different times during long and short rains seasons, 2008

Long rain season

Border crop distance (m)	Weeks after emergence								
	4	5	6	7	8	9	10	11	12
No border	12.2	7.8	15.2	14.4	8.9	2.2	20.0	20.0	13.3
0.5	7.8	6.7	6.7	12.2	14.4	2.2	27.8	12.2	11.1
1.0	6.7	8.9	12.2	6.7	10.0	0.0	8.9	7.8	5.6
1.5	7.7	7.8	15.2	14.4	8.9	2.2	20.0	20.0	13.3
2.0	8.9	6.7	12.3	5.6	13.3	0.0	10.0	14.4	6.7
2.5	10.0	10.0	10.0	9.9	10.0	0.0	7.8	14.4	9.9
3.0	20.0	8.9	12.2	5.6	12.2	4.4	4.1	14.2	11.1
$LSD_{(P\leq 0.05)}$	Ns	Ns	Ns	6.2	Ns	Ns	Ns	Ns	Ns
CV (%)	4.6	38.4	16.7	26.5	10.6	15.7	22.3	17.1	12.6

Short rain season

Border crop distance (m)	Weeks after emergence							
	4	5	6	7	8	9	10	11
No border	16.7	107.0	243.0	358.6	292.2	39	48.6	156.5
0.5	21.7	55.6	174.0	166.5	326.0	50.0	62.3	140.0
1.0	22.2	78.9	156.5	116.6	192.1	74.3	84.0	150.8
1.5	40.0	149.9	185.5	108.8	203.1	14.3	150.3	133.0
2.0	13.3	170.6	165.5	159.8	275.0	29.0	70.9	117.5
2.5	13.3	130.9	214.1	90.9	135.5	50.9	80.9	156.5
3.0	38.9	80.9	140.9	123.2	356.3	45.6	70.9	123.2
$LSD_{(P\leq 0.05)}$	Ns	Ns	Ns	121.2	Ns	Ns	Ns	Ns
CV (%)	29.1	28.7	29.0	21.5	13.7	47.5	31.2	46.1

4.4.1.2 Potato aphid population in water pan traps

The number of alate aphids caught in water pan traps differed between seasons. Higher number of aphids was recorded during short rain season than in long rain season (Table 4.4). The highest number of aphids was recorded in water pan trap placed inside the potato plot without border crop for both long and short rain seasons. The most abundant aphid species in the water traps was *Rophalosiphum maidis* (55%) and the least abundant was *Aphis fabae* (3%) during long rain season. However there were significant ($p \leq 0.05$ differences in the number of aphids among the different border crop placement. During short rain season, *Rophalosiphum maidis* (47%) was the most abundant species while *Myzus persicae* (2.5%) was the least abundant species (Table 4.4). There were no significant ($p \leq 0.05$) differences in the number of aphids in the water traps among the maize placement distances with respect to species and total aphid population.

During long rain season, peak aphid population was recorded at the 9th week after emergence while the lowest aphid population was at the first week after emergence (Table 4.5). Aphid population was not significantly ($p \leq 0.05$) different among maize borders placement distances over the sampling period except during the 7th week. During short rain season, the peak was attained at the 7th week after emergence of the potato while the lowest number of aphids was recorded on the first week.

Table 4.4: Mean number of aphids in yellow water traps in potato plots with varying maize border crop placement distances during long and short rains seasons, 2008

Long rain season

Border crop distance (m)	M.e	M.p	A.g	A.f	R.m	Total
No border	1.7	4.7	10.4	1.3	10.3	28.4
0.5	2.0	2.7	3.7	0.3	11.7	20.3
1.0	1.7	6.0	2.7	0.3	15.0	25.0
1.5	2.7	5.3	3.3	0.3	11.3	23.0
2.0	2.7	37	2.0	0.7	10.3	19.3
2.5	1.0	5.7	2.0	1.3	9.7	19.7
3.0	3.3	3.0	2.3	0.3	12.7	21.7
$LSD_{(P \leq 0.05)}$	Ns	Ns	Ns	Ns	Ns	Ns
CV(%)	6.7	21.0	23.6	41.7	19.6	8.8

Short rain season

Border crop Distance (m)	M.e	M.p	A.g	A.f	R.m	Total
No border	4.7	5.3	29.7	12.0	24.0	75.0
0.5	7.0	3.3	21.7	5.0	31.0	68.0
1.0	10.3	1.7	19.3	4.3	21.3	57.0
1.5	4.7	0.3	24	8.0	30.0	67.0
2.0	5.0	1.7	14	4.0	29.7	54.3
2.5	7.7	1.3	18.7	2.3	28.7	58.7
3.0	6.0	1.7	19.0	4.3	26.7	57.7
$Lsd_{(p \leq 0.05)}$	Ns	Ns	Ns	Ns	Ns	Ns
CV (%)	41.6	1.67	24.1	17.7	27.9	25.8

M.e = *Macrosiphum euphorbiae*; M.p = *Myzus persicae*; A.g = *Aphis gossypii*; A.f =*Aphis fabae*; R.m = *Rophalosiphum maidis* ns- Denotes not significant at (P≤0.5)

Table 4.5: Mean aphid population over time in water pan traps placed in potato plots with varying maize border crop placement distances at during long and short rains seasons. 2008

Long rain season								
	Weeks after emergence							
Border distance (m)	1	3	5	7	9	11	13	15
No border	0.3	0.3	5	0.7	12	0.3	0.3	2.7
0.5	0.0	1.7	2.3	0.0	1.7	0.3	2.3	1.7
1.0	1.0	0.7	0.3	1.0	0.0	1.0	2.3	2.3
1.5	0.3	0.3	2.0	1.7	0.7	1.3	2.3	3.0
2.0	0.3	0.3	0	0.3	1.0	0.7	1.0	1.0
2.5	0.3	0.7	0.7	0.3	1.0	0.0	2.0	3.3
3.0	0.3	0.7	0.7	2.7	2.7	0.0	2.7	0.7
$LSD_{(P\leq 0.05)}$	Ns	Ns	Ns	0.9	Ns	Ns	Ns	Ns
CV (%)	78.1	32.7	48.2	50.0	41.7	58.8	7.7	27.6

Short rain season							
	Weeks after emergence						
Border crop distance (m)	1	3	5	7	9	11	13
No border	0.3	8.3	12.3	6.3	13.3	6.3	2.3
0.5	1.0	7.3	5.7	13.7	6.0	4.0	4.3
1.0	0.0	5.0	8.7	8.0	3.0	2.0	4.0
1.5	0.0	10.0	5.3	8.0	8.0	2.7	3.3
2.0	1.0	5.3	5.0	6.0	2.3	4.0	1.7
2.5	0.0	9.7	6.3	5.3	2.7	5.67	1.0
3.0	0.3	8.0	4.3	8.3	5.7	4.0	0.7
$LSD_{(P\leq 0.05)}$	Ns	Ns	Ns	Ns	Ns	Ns	Ns
CV (%)	34.6	28.1	19.3	36.1	1.6	23.1	47.2

4.4.2 Effect of maize border crop placement distances on potato virus diseases

4.4.2.1 Effect of border crop placement distances on virus disease incidence

Virus disease symptoms observed included leaf roll leaf roll, erectiveness, brittle leaves, mild and severe mottling. Incidence of symptomatic plants increased as the potato crop matured (Table 4.6). However, the distance of the maize border from the potato crop had a significant ($p \leq 0.05$) effect on virus disease incidence only during the later stages of crop growth. Higher percentage of virus infected plants was observed during the long rain season compared to short rain season. There were significant ($p \leq 0.05$) differences in the mean virus disease incidence in plots with varying border crop distances during long rain season (Table 4.6). The highest virus disease incidence was recorded in plots without maize border crop while the lowest disease incidence was recorded in plots with maize border placement at 0.5m from the potato crop. Placement of maize borders at 0.5m from the potato plot significantly ($p \leq 0.05$) reduced virus disease incidence by 42.5% compared to non-bordered crop. There were no significant differences ($p \leq 0.05$) in the amount of disease during long rain season.

During short rain season, there were significant ($p \leq 0.05$) differences in virus disease incidence among the different maize border crop placement distances. The lowest virus disease incidence was recorded in plots with maize border crop placement at 1.0m while the highest was in plot with without border crop. Placement of border crop at 1.0m from the potato crop reduced the virus disease incidence by 47.5% compared to potato plants without border crop. The amount of disease differed ($p \leq 0.05$) significantly in plots with border crop and without border crop. Among the plots with border crops, there were no significant ($p \leq 0.05$) differences in the amount of disease. Plots without border crop had the highest amount of diseases while plot with border crop placement at 1.0m had the least amount of disease.

Table 4.6: Mean percentage virus disease incidence in potato plots with varying maize border crop placement distances in long and short rains seasons, 2008

Long rain season									
	Weeks after emergence								
Border crop distance (m)	4	5	6	7	8	9	10	Mean	AUDPC
No border	3.6	4.8	6.9	9.3	9.3	11.1	11.4	8.7	50.0
0.5	0.9	3.2	4.1	5.6	5.6	5.6	5.9	4.4	32.3
1.0	4.0	6.1	6.1	7.6	7.6	8.3	8.9	7.0	38.8
1.5	3.4	6.1	6.5	7.4	7.4	7.7	7.7	6.6	37.9
2.0	1.5	4.0	4.9	5.9	5.9	6.7	8.1	5.3	38.6
2.5	2.4	4.3	4.9	7.8	7.8	8.4	9.4	6.4	45.8
3.0	4.0	6.5	8.6	10.1	10.7	10.7	10.7	8.5	49.5
$LSD_{(P\leq0.05)}$	Ns	Ns	Ns	Ns	Ns	1.8	2.3	2.6	Ns
CV (%)	26.3	27.5	9.8	11	10.8	9.1	8.9	12.0	11.7

Short rain season							
	Week after emergence						
Border crop distance (m)	5	6	7	8	9	Mean	AUDPC
No border	0.8	3.2	4.0	5.6	6.7	4.0	16.6
0.5	0.0	0.9	1.7	3.1	4.0	1.9	7.7
1.0	0.0	0.6	1.4	2.5	3.6	1.6	6.3
1.5	0.0	1.3	2.6	3.1	3.6	2.1	8.8
2.0	0.3	1.9	2.4	3.4	4.6	2.5	10.2
2.5	0.0	0.8	1.5	3.0	3.3	1.7	10.4
3.0	0.0	1.4	2.3	4.4	5.4	2.7	10.7
$LSD_{(P\leq0.05)}$	Ns	1.4	Ns	Ns	1.9	1.1	7.7
CV (%)	87.1	9.3	9.9	9.0	11.5	5.5	8.0

4.4.2.2 Effect of maize border crop placement distance on potato virus titre

Viruses detected in tubers were potato leaf roll virus (PLRV), potato virus M (PVM) and potato virus X (PVX), potato virus A (PVA) and PVY. The most prevalent was PLRV in both seasons

(Table 4.7, 4.8 and 4.9). Lower virus titre was detected during the long rain season compared to short rain season (Table 4.7). During long rain season, PVY was not detected in potato tubers. The highest virus titre was recorded was recorded in plot with no maize border crop. There were no significant ($p \leq 0.05$) differences in virus titre among the border crop placement distances in respect to type of virus.

During short rain season plot without border crop had the highest virus titre compared to bordered plots (Table 4.7). Plot without border crops had 25% of the PVY titre but plot with border crop placement had the lowest overall virus titre. There were significant ($p \leq 0.05$) differences in PVY titre among plots with varying border crop placement distances. There were significant ($p \leq 0.05$) differences in virus titre of PVY with respect to maize border crop placement distances. Tubers harvested from plants with leaf roll symptoms had high levels of PLRV compared to tubers from plants showing mosaic symptoms and asymptomatic (Table 4.8 and 4.9). High level of virus titre of PVM, PVX and PVY were present in plants showing mosaic symptoms compared to tubers from plants showing leaf roll and asymptomatic and vice versa for plants showing PLRV. There were no significant ($p \leq 0.05$) differences in virus titre among the different border crop placement with respect to all viruses. PVY titre significantly ($p \leq 0.05$) differed in plants with mosaic symptoms harvested from plots with varying border crop distances. There was an increase of virus titre by 5.6% in the second control which was planted with seed tubers harvested from the first control during the first season.

Table 4.7: Mean virus titre in tubers harvested from potato plots with varying maize border crop placement distances during long and short rains seasons, 2008

Long rain season			
Border crop distance (m)	PLRV	PVM	PVX
No border	0.12	0.0	0.06
0.5	0.08	0.01	0.0
1.0	0.10	0.0	0.0
1.5	0.09	0.0	0.0
2.0	0.12	0.0	0.0
2.5	0.06	0.02	0.0
3.0	0.08	0.02	0.0
$LSD_{(P\leq0.05)}$	Ns	Ns	Ns
CV (%)	16.5	113.6	173.2

Short rains				
Border crop distance (m)	PLRV	PVM	PVS	PVY
No border	0.05	0.02	0.05	0.05
0.5	0.04	0.01	0.02	0.01
1.0	0.04	0.0	0.01	0.01
1.5	0.03	0.0	0.03	0.02
2.0	0.05	0.0	0.04	0.02
2.5	0.02	0.01	0.04	0.01
3.0	0.03	0.01	0.04	0.03
$LSD_{(P\leq0.05)}$	Ns	Ns	Ns	0.02
CV (%)	95.9	32.1	29.8	15.8

Table 4.8: Virus titre in tubers from potato plants showing various virus disease symptoms in plots with varying maize border crop placement distances during long rains season, 2008

Plants with mosaic symptoms			
Border crop distance (m)	PLRV	PVM	PVX
No border	0.11	0.02	0.01
0.5	0.04	0.0	0.0
1.0	0.02	0.02	0.0
1.5	0.04	0.02	0.0
2.0	0.05	0.01	0.0
2.5	0.07	0.01	0.0
3.0	0.05	0.03	0.01
$LSD_{(P\leq0.05)}$	Ns	Ns	Ns
CV (%)	42.8	136.2	96.2
Plants with leaf roll symptoms			
Border crop distance (m)	PLRV	PVA	PVM
No border	0.07	0.0	0.0
0.5	0.08	0.0	0.0
1.0	0.05	0.0	0.0
1.5	0.09	0.0	0.02
2.0	0.05	0.02	0.01
2.5	0.53	0.0	0.0
3.0	0.06	0.0	0.0
$LSD_{(P\leq0.05)}$	Ns	Ns	Ns
CV (%)	11.2	173.2	90.3
Plants without symptoms			
Border crop distance (m)	PLRV	PVM	PVX
No border	0.03	0.01	0.025
0.5	0.0	0.0	0.0
1.0	0.0	0.01	0.0
1.5	0.02	0.02	0.0
2.0	0.04	0.01	0.0
2.5	0.01	0.0	0.0
3.0	0.01	0.02	0.02
$LSD_{(P\leq0.05)}$	Ns	Ns	Ns
CV (%)	173.2	142	97.1

Table 4.9: Mean virus titre in tubers from potato plants showing various virus disease symptoms in plots with varying maize border crop placement distances during short rain season, 2008

	Plants with mosaic symptoms			
Border crop distance (m)	PLRV	PVM	PVS	PVY
No border	0.04	0.01	0.07	0.07
0.5	0.02	0.0	0.04	0.04
1.0	0.04	0.01	0.04	0.04
1.5	0.02	0.01	0.05	0.03
2.0	0.02	0.01	0.06	0.04
2.5	0.02	0.0	0.04	0.03
3.0	0.01	0.01	0.05	0.04
$LSD_{(P\leq 0.05)}$	Ns	Ns	Ns	0.02
CV (%)	25.1	17.7	7.2	16.7
	Plants with leaf roll symptoms			
Border crop distance (m)	PLRV	PVM	PVS	PVY
No border	0.07	0.01	0.02	0.04
0.5	0.06	0.01	0.01	0.0
1.0	0.04	0.01	0.02	0.01
1.5	0.04	0.01	0.01	0.01
2.0	0.05	0.01	0.02	0.0
2.5	0.05	0.0	0.01	0.0
3.0	0.05	0.0	0.01	0.01
$LSD_{(P\leq 0.05)}$	Ns	Ns	Ns	Ns
CV (%)	8.3	15.7	7.7	55
	Plants with no symptoms			
Border crop distance (m)	PLRV	PVM	PVS	PVY
No border	0.01	0.0	0.02	0.02
0.5	0.02	0.0	0.01	0.01
1.0	0.01	0.0	0.02	0.01
1.5	0.01	0.01	0.02	0.02
2.0	0.0	0.01	0.01	0.02
2.5	0.01	0.0	0. 01	0.02
3.0	0.02	0.1	0.0	0.01
$LSD_{(P\leq 0.05)}$	Ns	Ns	Ns	Ns
CV (%)	42.5	42.5	38	38.4

4.4.3 Effect of maize border crop placement distances on potato tuber yield

4.4.3.1 Effect of maize border crop on weight of tubers

Potato plots without maize border recorded higher tuber weight compared to plots with border crop (Table 4.10). The weight of seeds was more than that of ware or chatts although they were not significantly ($p \leq 0.05$) different among border crop placement. During long rains season, seed tuber grade constituted 56% of the total weight of tubers harvested. However there were significant ($p \leq 0.05$) differences in the weight of ware and total weight of tubers in plots with varying maize border placement distances. Plot with border crop placed at 0.5m from the potato crop had the lowest weight of total tubers. The total weight of tubers from plot with border crop placement at 0.5m was reduced by 43% of the total compared to tuber weight realized from the non-bordered plots.

During short rain season, the seed tuber grade constituted 66% of the total tubers harvested (Table 4.10). There were no significant ($p \leq 0.05$) differences in the grades of potato harvested except total tuber weight in respect to maize border placement distances. Plot with maize borders placed at 0.5m had the lowest tuber weight with a yield reduction of 48% compared to plots without border crops.

The asmptomatic plants produced more tubers than plants showing mosaic or leaf roll symptoms (Table 4.11 and 4.12). Plants showing mosaic symptoms had 3% more total tuber weight than plants showing leaf roll symptoms during both seasons. During long rain season, mosaic and leaf roll produced 21.7% and 24% respectively less total weight of tubers compared to asymptomatic plants (Table 4.11). However there were significant ($p \leq 0.05$) differences in weight of ware and total tubers among the different border crop placement distances for plants showing mosaic symptoms. Weight of ware. seeds and total tubers were significantly ($p \leq 0.05$) different among different border crops placement distances from potato plants for plants showing leaf roll symptoms.

Higher weight of tubers were harvested from potato plants that had no virus symptoms but there were more seed grade tubers than ware or chatts in plants showing virus disease symptoms. During short rain season, plants showing mosaic and leaf roll symptoms reduced tuber weight by 3.5% and 6.5% respectively compared to asymptomatic plants (Table 4.12). There were no significant ($p \leq 0.05$) differences in weight of ware, seeds, chatts and total tubers among the maize border placements. Higher weight of total tuber was harvested from potato plots with maize border placed at 1.0m for plants showing mosaic symptoms and for maize borders placed at 3m for plants showing leaf roll symptoms. During short rain season, plants showing leaf roll symptoms had higher weight of chatts grade than plants showing mosaic symptoms and asymptomatic plants (Table 4.13).

Table 4.10: Mean weight (kg) per plot of different potato tuber grades harvested from plots with varying maize border crop placement distances during long and short rain seasons, 2008

Long rain season				
Border crop Distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	51.5	41.8	1.6	94.4
0.5	12.1	38.3	3.3	53.7
1.0	29.2	45.0	4.0	78.1
1.5	25.0	46.5	2.5	74.0
2.0	33.1	37.6	2.6	73.3
2.5	33.5	55.7	1.5	74.1
3.0	33.0	37.6	3.5	90.7
$LSD_{(P\leq0.05)}$	13.2	Ns	Ns	12.4
CV (%)	4.2	3.8	21.0	3.0

Short rain season				
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	14.6	39.7	3.6	57.9
0.5	8.8	19.8	1.8	30.3
1.0	12.8	22.0	1.8	36.6
1.5	9.7	27.4	2.3	39.5
2.0	12.1	23.9	2.9	38.9
2.5	16.3	36.2	1.6	54.3
3.0	12.3	38.1	2.7	53.3
$LSD_{(P\leq0.05)}$	Ns	Ns	Ns	18.8
CV (%)	8.3	18.3	6.5	12.3

ns denotes not Significant at $P\leq0.05$

Table 4.11: Mean weight (g) of potato tubers harvested from plants showing various virus disease symptoms in plots with varying maize border crop placement distances during long rain season, 2008

	Plants with mosaic symptoms			
Border crop distance (m)	Ware (>55mm)	Seed(25-55mm)	Chatts (<25mm)	Total
No border	710.0	900.0	120.0	1700.0
0.5	100.0	560.0	60.0	800.0
1	190.0	630.0	530.0	1300.0
1.5	100.0	540.0	70.0	700.0
2	270.0	560.0	70.0	1000.0
2.5	200.0	550.0	60.0	900.0
3	90.0	600.0	40.0	800.0
$LSD_{(P\leq 0.05)}$	300.0	Ns	Ns	500.0
CV (%)	17.4	14.2	7.6	9.8

	Plants with leaf roll symptoms			
Border crop distance (m)	Ware (>55mm)	Seed(25-55mm)	Chatts (<25mm)	Total
No border	660.0	830.0	70.0	1560.0
0.5	110.0	430.0	60.0	590.0
1.0	780.0	690.0	50.0	820.0
1.5	160.0	590.0	80.0	830.0
2.0	140.0	480.0	100.0	720.0
2.5	170.0	570.0	60.0	800.0
3.0	220.0	620.0	70.0	940.0
$LSD_{(P\leq 0.05)}$	300.0	900.0	Ns	300.0
CV (%)	38.5	19.7	25.5	5.6

	Plants without symptoms			
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	1580.0	1400.0	80.0	3100.0
0.5	290.0	400.0	70.0	780.0
1.0	130.0	800.0	10.0	920.0
1.5	460.0	700.0	30.0	1170.0
2.0	490.0	600.0	30.0	100.0
2.5	390.0	800.0	80.0	1300.0
3.0	430.0	600.0	40.0	1090.0
$LSD_{(P\leq 0.05)}$	800.0	Ns	Ns	100.0
CV (%)	41	9.6	33.2	20.3

Table 4.12: Mean weight (g) of potato tubers harvested from plants showing various virus disease symptoms in plots with varying maize border crop placement distances during short rains, 2008

	Plants with mosaic symptoms			
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	140.00	380..0	30.0	520.0
0.5	0.0	310.0	20.0	330.0
1.0	100.0	480.0	30.0	610.0
1.5	110	430.0	20.0	560.0
2.0	60.0	360.0	50.0	480.0
2.5	50.0	460.0	30.0	540.0
3.0	150.0	550.0	80.0	770.0
$LSD_{(P\leq 0.05)}$	Ns	Ns	Ns	Ns
CV (%)	44.1	28.8	34.5	18.7
	Plants with leaf roll symptoms			
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	82.0	380.0	50.0	520.0
0.5	0.0	300.0	20.0	310.0
1.0	60.0	450.0	30.0	540.0
1.5	0.0	550.0	30.0	570.0
2.0	50.0	470.0	50.0	580.0
2.5	0.0	480.0	70.0	550.0
3.0	10.0	480.0	40.0	620.00
$LSD_{(P\leq 0.05)}$	Ns	Ns	Ns	Ns
CV (%)	17.4	9.4	45.9	5.8
	Plants without symptoms			
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	130	690.0	10.0	840.0
0.5	0.0	240.0	20.0	250.0
1.0	0.0	320.0	30.0	350.0
1.5	120.0	450.0	50.0	620.0
2.0	0.0	440.0	10.0	440.0
2.5	60.0	620.0	50.0	730.0
3.0	70.0	630.0	20.0	720.0
$LSD_{(P\leq 0.05)}$	Ns	Ns	Ns	Ns
CV (%)	31.5	23.8	43	18.5

ns denotes not significant at $P\leq 0.05$

4.4.3.2 Effect of maize border crop on number of tubers

Higher number of tubers (16%) was harvested in potato plots that had maize border placed at 2.5m from the potato crop. during long rain season (Table 4.13). Seed grade tubers produced constituted 61% of the total number of tubers harvested in short rain season. However, there were no significant ($p \leq 0.05$) differences in the number of tubers in plots with varying maize border crop placements. Higher number of tubers was harvested in potato plots with border placement distance at 3m from the potato crop during short rain season (Table 4.13). Seed grade tubers produced constituted 72% of the total number of tubers harvested in short rain season but, there were no significant ($p \leq 0.05$) differences in the number of tubers among plots with varying border crop placement distances. The proportion of chatts produced was 13% of the total number of tubers harvested.

Plants showing mosaic and leaf roll symptoms had 5% and 4% less number of tubers, respectively, than from asymptomatic plants (Table 4.14). There were no significant ($p \leq 0.05$) differences in the total number of tubers, for the different border crop placement distances for plant showing mosaic symptoms. However, number of ware, seeds and total number of tubers were significantly ($p \leq 0.05$) different for plants showing leafroll symptoms. The number of ware was significantly ($p \leq 0.05$) reduced in plots with varyng border crop distances for asymptomatic plants. During short rain season, mosaic and leaf roll produced 5% and 19.7% less total tubers compared to plants without symptoms (Table 4.15). There were no significant ($p \leq 0.05$) differences in the number of tubers in plots with varying border crop placement distances for plants showing mosaic, leaf roll and asymptomatic plants

Table 4.13: Mean number of potato tubers per plot from different tuber grades harvested from plots with varying maize border crop placement distances during long and short rain season, 2008

	Long rain season			
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	228.0	528.0	178.7	934.0
0.5	64.0	492.0	174.0	730.0
1.0	144.0	580.0	150.7	875.0
1.5	171.0	664.0	156.7	992.0
2.0	184.0	549.0	132.0	865.0
2.5	292.0	631.0	108.0	893.0
3.0	275.0	432.0	185.7	1032.0
$LSD_{(P \leq 0.05)}$	Ns	Ns	Ns	Ns
CV (%)	4.2	3.8	21.0	3.0

	Short rain season			
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	132.0	484.0	135.5	751.0
0.5	68.0	525.0	102.0	694.0
1.0	279.0	485.0	103.8	868.0
1.5	95.0	590.0	79.3	764.0
2.0	117.0	528.0	154.0	799.0
2.5	155.0	796.0	112.0	1063.0
3.0	79.0	1158.0	138.0	1375.0
$LSD_{(P \leq 0.05)}$	Ns	Ns	Ns	Ns
CV (%)	31.8	25.0	13.9	14.3

ns denotes not significant at $P \leq 0.05$

Table 4.14: Mean number of potato tubers harvested from potato plants showing various virus disease symptoms in plots with varying maize border crop placement distances during long rain season. 2008

	Plants with mosaic			
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	2.3	7.7	5.1	15.1
0.5	0.4	6.3	4.1	10.8
1.0	0.7	5.9	4.4	11.0
1.5	0.9	6.0	4.0	10.9
2.0	1.1	3.5	2.8	7.4
2.5	1.4	6.0	3.2	10.6
3.0	0.9	5.8	4.0	10.7
LSD$_{(P\leq0.05)}$	1.7	Ns	Ns	Ns
CV (%)	32.4	7.7	13.9	11.4

	Plants with leaf roll symptoms			
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	2.5	8.3	3.5	14.3
0.5	0.4	5.5	2.8	8.7
1.0	0.3	8.3	2.7	11.3
1.5	0.8	6.9	4.3	12
2.0	0.8	5.5	4.2	10.5
2.5	0.8	6.8	2.6	10.2
3.0	0.6	6.0	3.3	10.0
LSD$_{(P\leq0.05)}$	1.0	1.9	Ns	3.4
CV (%)	36.5	17	16.1	10.9

	Plants without symptoms			
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	2.7	8.2	4.6	15.5
0.5	0.5	7.0	5.0	12.5
1	0.3	7.3	3.7	11.3
51.5	1.0	5.7	2.7	9.4
2	1.1	7.0	1.8	9.9
2.5	1.1	8.5	3.0	12.6
3	1.5	7.3	2.7	11.5
LSD$_{(P\leq0.05)}$	1.3	Ns	Ns	Ns
CV (%)	33.3	7.3	20.3	12.5

Table 4.15: Mean number of potato tubers harvested from potato plants showing various virus disease symptoms in plots with varying maize border crop placement distances during short rain season. 2008

Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
Plants with mosaic symptoms				
No border	0.7	9.3	3.7	13.7
0.5	0.0	4.3	0.7	5.0
1.0	0.7	6.0	2.0	8.7
1.5	0.7	7.7	1.6	10
2.0	0.3	6.7	1.3	8.3
2.5	0.3	7.3	3.0	10.7
3.0	1.7	10.0	6.3	18.0
$LSD_{(P \leq 0.05)}$	Ns	Ns	Ns	Ns
CV (%)	60.1	29.3	37.4	24.5
Plants with leaf roll symptoms				
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	0.0	7.0	3.7	10.7
0.5	0.0	4.0	1.0	5.0
1	0.3	6.3	2.0	8.6
1.5	0.0	5.7	3.3	9.0
2	0.3	8.0	3.0	11.3
2.5	0.0	6.7	4.3	11.0
3	1.7	9.0	2.3	13.0
$LSD_{(P \leq 0.05)}$	Ns	Ns	Ns	Ns
CV (%)	66.7	6.8	39.8	7.3
Plants without symptoms				
Border crop distance (m)	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total
No border	1.7	6.0	4.0	11.7
0.5	0.0	4.3	0.3	4.6
1	0.7	6.0	2.0	8.7
1.5	0.7	8.0	2.0	10.7
2	0.7	7.7	0.7	9.1
2.5	0.3	7.3	2.3	9.9
3.0	3.7	10.0	1.7	15.4
$LSD_{(P \leq 0.05)}$	Ns	Ns	Ns	Ns
CV (%)	60.1	29.3	37.4	21.9

4.4.4 Effect of maize border crop on plant height

There were significant ($p \leq 0.05$) differences in plant height of potato among the border crop placement distances on the 8th and 9th week after emergence of potato during long rain season (Table 4.16). Tallest plants were in plot without border crop, while shortest plants were in plots with border crop placed at 1.5m. Placement of border crop at 1.5m from the potato plants reduced the height of potato plant by 20% compared to potato plant height in the plot without border crop. During short rain season, the tallest potato plants were in plots with border crop placement at 2.5m, while the shortest plants were in plot with border crop placed at 1.5m the height of potato plant with border crops placed at 1.5m was reduced by 12% compared to potato plants plot with a border placed at 2.5m. There were no significant ($p \leq 0.05$) differences in potato plant height during the potato growing period except on the 5th week..

Table 4.16: Mean potato plant height (cm) of potato plants in plots with varying maize border crop placement distances during long and short rains seasons, 2008

Long rain season							
	Week after emergence						
Border crop distance (m)	4	5	6	7	8	9	Mean
No border	45.6	58.4	75.3	86.4	108	119.2	82.1
0.5	33.2	47.4	64.6	77.7	91.7	101.8	69.4
1.0	42.1	56.2	74.4	84.5	102.1	111.5	78.5
1.5	34.2	46.6	56.8	68.2	76.3	90.3	62.1
2.0	37.4	54.6	70.0	85.4	100.7	108.2	76.0
2.5	34.2	46.3	61.2	72.7	85.8	94.8	65.8
3.0	39.0	52.6	66.9	74.6	91.5	104.9	71.6
$LSD_{(P\leq0.05)}$	Ns	Ns	Ns	Ns	12.48	9.78	11.7
CV (%)	10.0	3.7	3.3	1.2	2.3	3.5	1.2

Short rain seasons							
	Week after emergence						
Border crop distance (m)	3	4	5	6	7	8	Mean
No border	34.1	47.8	62.2	68.3	78.9	83.7	62.5
0.5	41.8	57.2	68.6	74.2	80.5	84.2	67.7
1.0	39.0	57.2	66.0	69.2	74.0	75.6	63.2
1.5	41.0	54.5	65.4	67.1	72.2	74.1	62.4
2.0	37.0	57.5	65.3	70.4	79.8	83	65.5
2.5	43.9	60.1	72.7	77.3	84.1	86.8	70.8
3.0	39.4	50.8	64.3	67.7	72.6	74.6	61.6
$Lsd_{(p\leq0.05)}$	Ns	Ns	69	Ns	Ns	Ns	Ns
CV (%)	10.1	8.4	5.1	5.8	8.0	6.2	6.8

4.5 Discussion

4.5.1 Effect of maize border crop distance on potato aphid population on leaves and waterpan traps

Five aphid species were found on the potato leaves. these were *Macrosiphum euphorbiae, Myzus persicae*, *Aphis fabae* and *Rophalosiphum maidis*. This is in agreement with finding by Muthomi *et al*. (2009) and Nyaga (2008) who found the same aphid species colonizing the potato plants in planting fields. The presence of high population of *M. euphorbiae* during long rain season agrees with findings by Machangi (2003) and Muindi (2008) who found that this aphid species is the most dominant species on potatoes leaves. This can be attributed to prevailing cold weather condition during the first season which favours reproduction of the aphid (Appendix 1). The study also revealed that *Aphis gossypii* was the most prevalent species during short rain season is in agreement with findings by Rongai *et al.* (1998). Nderitu and Mueke (1986) found a high number of *Aphis gossypii* during short rains compared to long rain season which can be attributed to high temperature experienced during the short rain season as reported by Asin and Pons (2001). Blackman and Eastop (2007) reported that *Aphis gossypii* reproduces at a very high rate in warm tropical climate.

The high number of aphids that were recorded in plots with no border crops contradicts findings by Fereres (2000) that border crops do no reduce the number of aphids in the primary crop. This can be attributed to the ability of the border crops to block the alate aphids from reaching the host plant by acting as a natural barrier (Srinivas and Elawande, 2006, Boiteau *et al.*, 2008).

Rophalosiphum maidis was the most abundant aphid species in water traps in the two seasons. . This disagrees with finding by Muindi (2008) who reported Aphis gossypii as the most abundant aphid species in water traps. High number of this aphid species can be attributed to the effect of maize used as border, which is a major host of the *R. Maidis* (Blackman and Eastop 2007). The prevailing hot weather and declining host nutrition and overcrowding may also have triggered reproduction of the winged morphs which flies off in search of hosts as reported by, Braendler (2006), Cocu *et al.* (2005) and Lombaert *et al.* (2006). The difference in aphid peak population may be attributed to differences in growth period in the potato crop which was influenced by the weather condition and also quality of food (Muller *et al.* 2001). McDonald *et al.*, (2003) found that flight of aphid activity increased 3-4 days after rains while high population of *A. gossypii* and other vectors of Tobacco etch virus were caught when there was a large acreage of pepper.

4.5.2 Effect of maize border crop distances on virus diseases

The study found that there was high prevalence of virus incidence in plots without border crops during both long and short rains. This can be attributed to border crops arresting of the aphids or reducing the virus content of the infected aphids through stylet probing of the border crop (Ebwongu *et al.*, 2001; Hooks and Ferères 2006; Oasakabe and Honda, 2002).

Potato leaf roll virus was detected in potato tubers during both seasons in high virus titre. The mode of transmission of this virus makes it difficult to control using border crops (Difonzo. *et al*, 1996), but the virus as being one of the most widespread in the potato (Nyaga 2008). There were higher cumulative virus titres in short rains than in long rains. This can be attributed to high population of aphids found on leaf sample and also high peak of aphids being reached when the crop was still susceptible to virus infection (Difonzo *et al.*, 1996). Higher PVY titre was detected in plots without border crops than in the plots with a border crops. This can be attributed to the aphid losing some of the virus inoculum on its stylet while it is probing the border crop (Oslon *et al., 2006:* Hooks and Fereres, 2006). Potato virus Y was detected in tubers harvested during short season and it was lacking in long rains. This can be attributed to high population of aphids during short rain season. The aphid threshold of 3-10 aphids per 100 potato leaves had been reached when the crop was still prone at the vegetative stage (Capinera, 2001; Thomas 2002).

Use of chemical can be encouraged when the aphid threshold of 3-10 aphids per 100 leaves is reached early during to prevent spread of viruses to the tubers (Zhu *et al.,* 2006). Plants that showing mosaic and leaf roll symptoms had higher virus titre than asymptomatic plants and this is in agreement with findings by Nyaga (2008) that potato plants showing viruses symptoms had higher virus titre than asymptomatic plants. This can be used by farmers to select asmptomatic plants that have a low virus load for use as seed (Gildemacher *et al*., 2007; Kabira *et al*., 2006).

4.5.3 Effect of maize border crop placement distances on potato yield

There was a significant reduction in the weight of the total tubers in all seasons although the number of tubers was not affected by the border crop. Yield reduction in some plots with border crop may have been as a result of shading effect by the maize. There was a reduction in the weight of tubers in the symptomatic plants compared to asymptomatic plants. This can be due to effect of high quantity viruses of symptomatic plants and this is in agreement with findings by Hamm (1999) who found potato PLRV produced 60% less yield.

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CHAPTER 5: GENERAL, DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.5.3 General discussion

The study revealed that the potato farmers had small farm parcels of between two and five acres in Imenti Noth, Meru Central, Nyeri North, Nyandarua South, Nakuru North and Narok North districts. The study also revealed that farmers were growing potatoes on more than one acre of land. This implies that farmers may not undertake crop rotation resulting in high incidence of diseases and pests (Kinyua *et al.*, 2001). The study showed that farmers were planting other local varieties in addition to Tigoni and Asante. Selection of the variety to been grown by the farmers was based on yielding potential, disease resistance, skin colour, storability and also market demand. This criterion can form a basis for future research of new varieties which can be regionalized. The study also revealed that farmers were using own produced seed tubers and from markets which were contaminated with viruses up to 100% although only 50% of the farmers were aware of aphids and virus symptoms in the farms. Failure by the farmers to control aphids and the high viruses' titre contribute to an enhanced degeneration of the seed potatoes (Kabira *et al.*, 2006; Gildemacher *et al.*, 2007). Uses of clean seed potato is a key determinant of potato yield and hence there should be consolidated effort to enable small farmers to produce quality seed (Kidanemarium *et al*, 1999; Olubayo *et al.*, MOA, 2008_a).

Maize border or barrier crop is a cheap cultural method that can be adopted by the farmers in the management of aphids and non-persistently transmitted viruses in seed potato. The aphid species identified infesting potatoes were Myzus *persicae*, *Macrosiphum euphorbiae*, *Aphis gossypii*, *Aphis fabae* and *Rophalosiphum maidis.* These aphids are important vectors of potato viruses that cause considerable losses in quality and quantity of tubers. *M. euphorbiae* was the most abundant species on leaves during long rain season while *A. gossypii* was the most abundant species on leaves during short rain season. The high number of *M. euphorbiae* on leaves during long rain season and *A. gossypii* during short rain which is in agreement with findings by Muindi (2008). The high population of *A. gossypii* compared to *M. euphorbiae* is can be attributed to high temperature which is favourable for reproduction of the aphid as reported by Blackman and Eastop (2007). The study also revealed that non-bordered potato plots had high population had a high number of aphids compared to bordered plots. Placement of maize border crop at 1.0m had the least number of aphids in both season.

The study also revealed that non-bordered crops had a higher virus incidence and virus tite than crops that had maize borders. It can be implied that border crops had a part to play in reducing the virus inoculum in the viruferous aphid before probing on the potato plants. The viruses that were detected during the potato growing period seasons were potato leaf roll virus, potato virus M, potato virus X , potato virus A and potato virus S and potato virus Y. Low virus incidence was recorded in potato plots that had maize border crop placed at 0.5 and 1.0 metres for the potato crop. Since virus titre of PVY was least in potato tubers harvested from plot with maize border crop placement at 0.5m and 1.0 metre it is clear that farmers can use these two distances to control the virus diseases in their farmers. However potato plot with maize placement distance had lower weight of tuber harvested compared to tubers harvested from potato plots with border placement at 1.0 metres. It can then be deduced that placement of maize border crop at 1.0m would result in a farmer gaining in terms of high yield and reduction of virus diseases. There was an increase (5.6%) in vithe virus titre in seed tuber grade harvested from the second control in the second season. this implies that the virus build up would go up with each consecutive planting as long as the control of vector is not done.

The study showed that there was higher virus titre in tubers from plants that were showing various virus disease symptoms compared to tubers from plants showing no virus symptoms. Among the diseases the plants that were showing leaf roll symptoms had a higher reduction in weight of tubers than plants showing mosaic symptoms. It can be deduced that potato leaf roll diseases causes more yield reduction in tuber yield that mosaic virus diseases. It can be implied that selection of tuber based on visual virus disease observation would result in seed tubers with low virus load. Training of farmers can be done on virus disease symptoms which can be applied in selection of seed in maize bordered potato crop.

5.2 Conclusion

This result of this study shows that recycling of farmers' own seed potatoes and purchases from markets resulted in low yield although farmers were carrying out most of the agronomic practices. Low yields of potatoes achieved may be attributed to high prevalence of viruses in the farmers' produced seed tubers. It was evident from the result of experiment that farmers can plant maize border placed at 1.0m to reduce the risk of aphids transmitting potato viruses to the main crop and also get high yield of seed potato. Selection of healthy looking plant can further reduce the probability of transmission of viruses from one season to another.

5.3 Recommendations

Based on the above conclusion the following recommendation can be made:

1. More studies can be carried out to determine the length of time seed produced through application of border cropping can be planted before yields are reduced to uneconomical level.
2. Investigation can be carried out to determine the best crop to be planted in the distance left between the potato and the maize border for maximum utilization of land.
3. Farmers should be encouraged to select potato plants to be harvested as seed when the crop is still actively growing for use consecutive season potato production.
4. Further study can be done to determine virus type and levels of high yielding local varieties and possibility of determining possible resistance to viruses
5. Local varieties that the farmers are growing can be cleaned, multiplied and then returned to the farmers.
6. Group approach in seed production should be encouraged for ease of training and supervision of such groups during the time seed is in the field.
7. An aggressive campaign should be launched to create awareness on effects of aphids and potato tubers viruses on yield of potatoes.

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APPENDICES

Appendix 1: Weather data for NPRC, Tigoni during long and short rains, 2008

Year	Month	Rainfall (mm)	No. of rainy days	Relative humidity (%)	Temperature (°C)
2008	April	323.1	11	69.2	15.4
2008	May	51.3	7	67.2	15.5
2008	June	8.3	3	70.8	12.9
2008	July	60.5	12	77.1	12.6
2008	August	14.0	4	66.8	19.0
2008	September	79.8	6	68.9	15.5
2008	October	194.2	13	73.4	15.4
2008	November	159.6	8	69.9	15.9
2008	December	0	0	88.3	16.7
2009	January	43.4	3	65.2	16.1
2009	February	24.5	2	64.5	16.4
2009	March	57.4	2	65.1	17.1

Source: NPRC KARI Tigoni, 2008

Appendix 2: Questionnaire used to gather information on aphids and viruses diseases at the farm level in central and eastern provinces of Kenya

Date---------month -------------2008

a. Personal details

1. Name of farmer --

2. Gender Male/Female --------------

3. Administrative location: Province ---------------District ------------------Division ------------------
Location-----------------------------Sub-location----------------------Village--------------------------

b. General information

1. Agro-ecological Zone-------------------

2. Total area of the farm (ha) ---------------

3. Crops grown on the farm in order of priority
   1. ------------------------
   2. ------------------------
   3. ------------------------
   4. ------------------------
   5. ------------------------
   6. ------------------------
   7. ------------------------

c. Potato cultural practices

1. Area under potato (Ha) ------------------

2. Potato varieties grown
   1. ------------------------
   2. ------------------------
   3. ------------------------
   4. ------------------------

3. Preferred varieties
   1. ------------------------

2. ------------------------

3. ------------------------

4.------------------------

4. Source of seed:

1. Own seed ------------------------- 2. Markets----------------------

3. Buy from neighbours------------ 4. Research institution (specify) -------------

5. Markets ---------------------------- 6. Others -------------------------

5. Do you select seeds? Yes------No -----------

6. Grades of seed potato selected

1. -----------------

2. -----------------

3. -----------------

4. -----------------

7. Fertilization

1. Use manures Yes --------- No-----------

2. Use of fertilizers Yes ----------No----------

8. Fertilizer used

1. ------------------------

2. ------------------------

3. ------------------------

4. ------------------------

5. -------------------------

6. ------------------------

9. Diseases observed in potato

1. ------------------------

2. ------------------------

3. ------------------------

4.------------------------

5. -------------------------

6. ------------------------

10. Pests observed in potato

1. ------------------------
2. ------------------------
3. ------------------------
4. ------------------------
5. -------------------------
6. ------------------------
7. ------------------------

11. Methods of controlling diseases and pests

1. ------------------------
2. ------------------------
3. ------------------------
4. ------------------------
5. -------------------------
6. ------------------------
7. ------------------------

12. Chemicals used in pest and diseases control

1. ------------------------
2. ------------------------
3. ------------------------
4. ------------------------
5. -------------------------
6. ------------------------
7. ------------------------

13. Seen aphids on potato? Yes---------- No----------

14. Seen virus symptoms on potato plants? Yes---------- No----------

(show photograph of virus symptoms)

15. Method of harvesting: Dehaulm Yes-------- No-------

16. Yield of potato (110 Kg bags) ---------------------------

17. Do you store potato)? Yes --------No --------

18. How do you store potato?

1. Wooden store------- 2. In sacks -------------

3. Underground storage 4. Other methods--------------------

19. Do you store seed potatoes? Yes---- No----. How long do you store potato seeds?-----Months

20. Do you wait until tuber seeds sprout? Yes ---------- No----------

21. What is the approximate cost of each control of diseases and pests? Kshs-----------

22. What characteristics would you require in new potato varieties?

1. ------------------------

2. ------------------------

3. ------------------------

4 .------------------------

23. What information would you require to manage aphids and viruses effect? ---------------------
----

24. Constraints faced in potato production

1---

2---

3---

d. Social-economic information

1. Do you sell potato? Yes ------ No--------

2. Where potato are sold

1. ------------------------

2. ------------------------

3. ------------------------

4.------------------------

3. Cost of 110kg potato bag (Kshs) -----------------------

4. Cost of 50kg seed potato (Kshs) ----------------------

5. Who make decision on the farm operations?

Husband ----------Wife-------------- Others (Specify)--------------------

6. Source of information on crop protection practices

1-------------------------------------

Appendix 3: Questionnaire used to gather information on aphids and virus diseases at the market level in retail markets

Date---------month -------------2008

i. Personal details

1. Name of Trader ---
2. Gender Male/Female --------------
3. Name of the town/city ---------------------------
4. Name of the market -------------------------------
5. Do you sell ware potato? Yes-------- No---------
6. Source of ware potato sold
   1. -------------------
   2. -------------------
   3. -------------------
7. Do you sell seed potato? Yes-------- No---------
8. Source of seed potato sold
   1. -------------------
   2. -------------------
9. Do you select seeds? Yes------No -----------
10. Grades of seed selected and sold
    1. -----------------
    2. -----------------
    3. -----------------
11. Cost of 15Kg tin (Ksh) ------------
12. Preferred potato varieties
    1. ------------------------
    2. ------------------------
    3. ------------------------
13. Constraints faced in the selling of potato
    1---
    2--------------------------------------

Appendix 4: Procedure of carrying out Double Antibody-Sandwich Enzyme Linked Immunosorbent Assay (DAS-ELISA) technique to detect potato viruses

Add 100 µl purified γ-globuli in coating buffer (coating solution) to each well of the plate and incubate at 37°C for 3-4 hours

↓ Carefully wash plates sequentially in PBS-T and carefully dry then before the next step

Add 100µl test sample in phosphate buffered saline solution-in Tween (PBS-S) and 2% Polvinyrrollidane (PVP) and incubate overnight at 4^0C

↓ Wash plates sequentially in PBS-T and carefully dry them before the next step

Add 90µl of the enzyme labeled γ-globulin (conjgate solution) and incubate a 37°C for 3-4 hours

↓ Wash plates sequentially in PBS-T and carefully dry them before the next step

Add 90 µl of P-ntophenyl phosphate substrate in diethanolamine buffer And incubate for 30-60 minutes at room temperature

↓

Visual assessment of yellow colour in the Elisa plate wells

↓

Photometric measurement of absorbance at 405 wavelength using the Elisa ready

Source: CIP, 2007